PERIODICAL
UNIVERSITY OF HAWAII
LIBRARY

OUTLOOK
ON
AGRICULTURE

Volume III Number 1

Winter 1960

3
8

The design in linocut on the cover is a composite of drawings from two medieval manuscripts. In the centre is a figure from the works of Matthew Paris, who entered St. Alban's as a monk in 1217. Surrounding this, depicting farming activities throughout the year, are drawings based on MS. from the Benedictine Abbey of Sweifalten, circa 1162.

Articles published in this journal are the copyright of Imperial Chemical Industries Limited. Permission for their reproduction may be granted on application to the Editor.

A PERSONAL MESSAGE

from the Director-General of the Food and
Agriculture Organisation of the United Nations

FREEDOM FROM HUNGER CAMPAIGN

I am most grateful to the publishers of Outlook on Agriculture *for devoting this issue to the study of world food and population problems and their solution as a contribution to the Freedom from Hunger Campaign of the Food and Agriculture Organisation of the United Nations.*

The Campaign is being supported by the United Nations and its other specialized agencies and by a wide range of non-governmental organizations, private associations and industrial groups. The present initiative by Imperial Chemical Industries Limited is most appreciated, and we look forward to similar activities on the part of many other bodies.

The articles published here focus attention, from the viewpoint of this great industrial concern, on the many special problems encountered in improving or increasing agricultural and livestock production and indicate what can be done through the coming years to provide food for the rapidly expanding world population.

B. R. SEN
Director-General

Digitized by the Internet Archive
in 2023 with funding from
Kahle/Austin Foundation

https://archive.org/details/outlook-on-agriculture_winter-1960_3_1

OUTLOOK ON AGRICULTURE

VOLUME III · WINTER 1960 · NUMBER 1

PAGE

2 *Editorial: World Food and Population*

9 *Increasing World Food Supplies through Greater Crop Production*
H. L. Richardson, M.Sc., Ph.D., D.I.C., F.R.I.C.

23 *The Contribution of Crop Protection to Increased World Food Supplies*
E. Holmes, M.Sc., Ph.D., F.R.I.C.

39 *Veterinary Science and the World's Food* G. V. Short, M.R.C.V.S.

51 *Book Reviews*

Communications should be addressed to the Editor, E. J. McNaughton, B.Sc. (Hons.), B.Sc. (Agric.), Imperial Chemical Industries Limited, Jealott's Hill Research Station, Bracknell, Berkshire, England

WORLD FOOD AND POPULATION

There can no longer be any doubt that the problem of feeding the world's rapidly increasing population has become one of the most serious of our times. Directly or indirectly it concerns all nations, but at the moment it is most acute and urgent in the less developed countries where food supplies have always been deficient and now seem likely to become more so unless remedial measures are taken without delay. In the course of the last two decades various governments and international organizations have done much to relieve local shortages of food and have provided assistance in other ways, but it is becoming increasingly clear that the only satisfactory solution lies in the rapid improvement of agriculture within the hungry countries themselves, and this cannot be achieved without technical and financial aid from outside on an unprecedented scale.

The current and future situation in its manifold aspects was reviewed at a symposium on "World Food and Population" held in Cardiff on September 5th 1960, at the annual meeting of the British Association for the Advancement of Science. This was the first time that a day had been devoted to a single theme, demonstrating the Association's awareness of the magnitude and urgency of the problem. Sir George Thomson, the President, took the chair, and a number of distinguished scientists addressed the meeting. A summary of what was said follows.

In a short introductory address Sir George said that the upsurge in the world's population was largely the result of medicine's success over many of the potentially fatal diseases. Scientists therefore had the duty of finding remedies for the difficulties they had caused—that of feeding this rapidly increasing multitude. The immediate problem might be regarded as political rather than scientific, but the politician had to deal with the toughest and most resistant material in the world—human nature—and scientists ought not to wish the problem off on to him. It is easier to solve a technical problem than a human one, he said.

CURRENT FOOD SUPPLY SITUATION AND PRESENT TRENDS

To what extent do current food supplies meet present population needs? What justification is there for the statement that at least half the world's population is either undernourished or malnourished? These were the questions that Dr. Norman Wright, Deputy Director-General of the F.A.O., set out to answer. As a "yardstick" in assessing the adequacy of present-day diets in other countries, he took the level of 2800 calories per head per day, this being the figure at which British adults and children start to lose weight.

The food supplies of 21 countries, located in Europe, North America, Oceania and the River Plate area, accounting for some 20% only of the world's population, exceed a calorie level of 2800. In contrast those of 50 countries, accounting for 60% of the world's population, actually fall below 2200 calories, and for about half of the population of these lands the level does not even attain 2000 calories. Only eight of these countries are in Europe; the remainder are in the underdeveloped regions of the Near East, the Far East, Africa and Latin America—chiefly in the tropics and subtropics. Food requirements in such zones are lower than those of Britain, for such factors as higher environmental temperatures and the smaller stature of most tropical inhabitants reduce their food needs. Nevertheless the existing differences in food consumption levels are far too large to be accounted for on this basis, and acceptance of these levels would condemn the underdeveloped countries to a permanent and possibly an increasingly serious state of undernutrition.

Undernutrition and its Effects

Dr. Wright strongly emphasized the adverse effects of undernutrition. In countries where this has been severe there is not only weight loss and reduction in physical activity, but lack of mental alertness, apathy and depression, leading in extreme instances to loss of moral standards. There is also lowered resistance to tuberculosis, and the course of infectious diseases is apt to be less favourable.

Moreover, a deficiency in the total food supplies of a country does not reveal the degree of undernutrition of the poorer fed sections of the community. Populations living at a subsistence level are particularly vulnerable to seasonal changes in food production, and catastrophically so to crop failures. In many of the less-developed countries famines are still a constant threat and temporary local food shortages are endemic. The F.A.O. has received an average of at least one appeal annually for assistance from countries, parts of whose territories have been subjected to, or threatened by, famine or serious food shortages.

In most underdeveloped countries food is inadequate in quality, leading to malnutrition as well as to undernutrition. Cereals and starchy roots form too high a proportion of the diet—over 75% in the Far East compared with 25% in North America. On the other hand the proportion of animal products—milk, meat, eggs and fish—is too low, being only 5% in the Far East as against 40% in the North American diet. These differences are reflected in the consumption of protein, the figures for total protein (expressed in grams per head per day) falling from 92 in North America to 57 in the Far East, and for animal protein falling still more strikingly from 66 in North America to only 7 in the Far East.

Owing to this lack of variety, the diets of the less developed countries tend to lack vitamins and essential mineral constituents and this in turn leads to the incidence of specific deficiency diseases. Probably the most widespread and damaging is kwashiorker, found most frequently in children between weaning and 4–6 years of age; unless promptly given supplementary protein the child usually dies. A less acute but more prevalent condition is "pre-kwashiorker." There is probably no African child who has not suffered from such a deficiency at some period of its life, and the condition is prevalent in many other parts of the world where a shortage of animal protein exists. Other common deficiency diseases are avitaminosis A, which causes blindness; pellagra and nutritional anaemia.

Future Food Requirements

In Dr. Wright's view the statement that half of the world's population is underfed is broadly justified. If this is accepted, what prospect for improvement can we see in present food production trends?

Contrary to widely held belief, world food production is currently increasing at a slightly faster rate than world population, but production per head in Latin America, Africa and the Far East is still slightly less than before the war. One consequence of these shortfalls is that exports of food from the less developed countries have fallen and many such have become food importers. The effect of these changes, however, is almost negligible in relation to needs. Present diets are inadequate and in estimating future requirements we must not only allow for the needs of the rapidly increasing population but make good existing deficiencies.

Every 100 million added to the population will need about 13 million tons of additional cereals and 14 million tons of animal products; but if allowance is made for bringing the present world diet up to a reasonable level, it appears that by 1980 we shall have to increase the world's cereal production by one-third and double the production of milk, meat, eggs and fish. These figures are based on a 1980 world population of just over 4000 million, compared with just under 3000 million now. By the year 2000, assuming that the world population will reach 6000 million, the needed increases will have risen to over 100% for cereals and over 200% for animal products; indeed, to achieve a fully adequate level for all countries the latter figure would have to be stepped up to 300% or more. If such increases are to be met, drastic measures will be essential.

Possible Solutions

One solution suggested is the distribution to scarcity areas of the grain surpluses produced in the more developed countries. During the past decade these mounted to over 125 million tons—enough in theory to supply the full calorie needs of some 45 million people for a year. But there would be insuperable difficulties in achieving its widespread distribution. Once it has been distributed, only an annual surplus of the order of perhaps 10 million tons would be available for disposal, and in bad seasons none at all.

It would also require a revolution in the dietary patterns of the scarcity areas to enable the distribution of surplus grains to affect appreciably their calorie levels. Moreover, to alleviate malnutrition what are required are protein-rich foods, not cereals, and the world's surplus of condensed, evaporated and dried milks in 1959 was only about 120 thousand tons. Grain surpluses have proved to be an invaluable aid in the relief of famines and severe food shortages, but they never should, and never could, be relied upon to provide a long-term solution to the world's food supply problems.

Another suggested panacea is the world-wide adoption of vegetarian diets. Its protagonists point out that the conversion of plant into animal tissues is wasteful and that the direct use of plant tissues as human food will substantially increase food resources. But domesticated animals obtain most of their food from herbage and by-products that are inedible to man, and, in their passage through the animal, the proteins of such materials are improved in quality, concentrated, and made into a more readily available form. The mineral constituents and vitamins are also concentrated, thus conferring on many animal products an exceptionally high value as "protective" foods. Finally, from an agricultural aspect, livestock play an essential role in maintaining and indeed in increasing soil fertility.

Indeed, it is possible that the universal adoption of vegetarian diets would exacerbate rather than solve the problem. The tendency is for populations to increase the proportion of animal products in their diet as they progress from poverty to plenty and it is inconceivable that the countries of North America and Europe should revert to the dietary pattern of the 1850s. The only effective and long-term solution, Dr. Wright concluded, is to increase food production within the less developed countries themselves.

POPULATION PROSPECTS AND THEIR IMPLICATIONS

Professor D. V. Glass, University of London, drew attention to the population background against which the nutritional, economic and social needs have to be considered in discussing the changes that might occur during the balance of the present century.

According to the United Nations projections, world population has been growing at an increasing rate, rising from about 0·5% per year in the first half of the nineteenth century to about 1·6% per year in the 1950s. If this latter rate persisted the world population would double itself in 44 years and rise to some 5000 million by the end of the century, but on the U.N. medium projections, involving the assumptions of declining mortality and some fall in fertility in high-fertility countries after 1975, it might reach 6000 million.

Even more striking than the absolute numbers are the speed of the increase and the differences in relative growth between regions with different current levels of living. Between 1900 and 1950 world population increased by 1000 million. A further increase of that amount is likely to be achieved between 1950 and 1970, and still another in the twelve years thereafter. Much of that projected growth would occur in countries which, at present, have very low levels of living. Thus, in the developed regions as a whole, numbers are expected to increase by about 70% between 1950 and the end of the century, whereas in Africa the medium projections imply an increase of over 150%; in Asia 180%; and in Latin America over 250%.

Control of Fertility

Birth control has frequently been advocated as a part solution to the problem of over population, but Professor Glass believed that during the balance of this century we cannot count heavily upon the contribution from it, especially in early stages of economic and social development.

One reason is that mortality may fall more rapidly than is assumed, for the drive to reduce the death rate is likely to become more intense. Even if birth control were accepted fairly widely in the near future, populations would continue to grow substantially for a considerable time while children under 15 years were passing through the child-producing ages. Moreover, falling mortality itself will tend to increase the proportion of young people, since reductions in death rates will occur mainly among infants and children.

When a decline in fertility did set in, the ratio of dependent to active age groups would fall fairly quickly, but it would be unrealistic to count upon the full advantage of such a change in age composition. For instance, the spread of compulsory education will make the under 15s a more fully dependent group, and the wider provisions of social services and pensions may have a similar effect at the other end of the age scale.

Professor Glass doubted if there is, as yet, much basis for expecting a rapid adoption of birth control and of a small family pattern in societies which, so far, have shown little movement in that direction. While many countries will no doubt come to realize the need, the explicit recognition will take time and the first measures are likely to be hesitant. Numerous obstacles—technical, social, administrative and others—must be overcome before birth control can be successfully introduced and spread among rural and illiterate peoples. In particular, a simple and reliable method of contraception has yet to be found. The provision of advice and assistance through the U.N. scarcely seems practicable at present, and it is certain that proposals for such assistance would be opposed by many member countries on religious grounds.

But even if birth control policies are adopted and assistance is obtained, a realistic programme for international action in the field of development would need to allow for the continued increase of world population for a sizeable period at the rate of 1·6% per year or higher. To meet the present rate of population growth and to even out inequalities between societies in levels of living will require a very wide range of measures, but as the basis of economic and social development the provision of more ample food supplies will be essential.

ECONOMIC CONDITIONS FOR GREATER OUTPUT

Professor W. A. Lewis, Principal of the University College of the West Indies, outlined the economic conditions for greater output. The most important of these is expanding demand. If farm output is to grow faster than population, then non-farm demand must also grow faster than population, or there will be depression in agriculture. Expansion of the non-farm sector of the economy is a prerequisite of agricultural prosperity, to provide both markets for produce and employment for surplus farm population.

Another major need is to ensure that profits from the land go to the farmer rather than to landlords or creditors. Rents are frequently far too high, and when farmers run into debt their only recourse is to moneylenders who charge exorbitant rates of interest for cash they loan.

The poorer countries do not spend enough on agricultural research and developments, and tend to concentrate expenditure on export crops accounting for only a fraction of farm output.

Capital requirements are enormous not only for direct improvements of farms, but for the provision of public and private services such as roads, irrigation, processing mills, warehouses and electric power. Public capital and publicly supported financial institutions are necessary if agriculture is to receive adequate investment. The United States should, said Professor Lewis, be making grants and loans to the poorer countries for all the next 25 years.

Large-scale organization is needed to ensure that farmers have access to knowledge and services as well as capital. This requires considerable government initiative, but all too often this is lacking. In nearly every underdeveloped country, said Professor Lewis, the post of Minister of Agriculture had been filled by a political nobody. Permanent officials were often inefficient. Government action may be necessary to compel farmers to use better seeds, to spray their crops or to adopt other improved cultural practices, but experience has shown that attempts to do so will fail if the directors are incompetent.

LAND RESOURCES

Dr. L. Dudley Stamp, professor emeritus of the University of London, dealt with the effects of the rapidly increasing pressure of population on land resources. The problem, he said, is not merely one of feeding the people: with rising standards of living there is often fierce competition for available land—for social, industrial and other purposes as well as for agriculture—and because world population is now increasing at the rate of some 45 million yearly, the problem of planning the best use of land resources is staggering and urgent.

About 70% of the earth's land surface is uninhabitable in the sense that it is permanently incapable of producing crops to sustain human needs. The remaining 30% can be described as "potentially cultivable." This comprises the 9% to 10% of the total land surface that is already cultivated and the unexploited balance which includes vast areas of equatorial forests and tropical savanna, and grassland where many problems remain to be solved before any can become either cultivable or cultivated. In other words, the present world population is supported by cultivating about one-tenth of the land surface, and only a further two-tenths of the whole remain that might perhaps be used to sustain human life.

But contrasts between one country and another are very marked, and it is the national rather than the world level that is the more important one to study. If the land surface were divided equally among the population, every human being would have a share equal to 12·5 acres, of which 4·0 acres is "potentially cultivable" including 1·1 acres as the land actually used. The land resources of any country may be crudely assessed on the same basis and the extreme contrasts between the "haves" and the "have nots" then become obvious. Deducting the acres per head actually cultivated from the "potentially cultivable," the world has 2·9 acres per head that are not cultivated for food production. Canada has no fewer than 18·0 acres and the U.S.A. 3·0, both countries now producing in excess of home requirements; but India has only 0·25 acre. Great Britain has 0·05 acre and Japan a mere 0·03 acre per head.

Shortage of land is the primary reason why land planning in all crowded countries is essential. It calls for a careful assessment of a wide range of factors. What is needed is a detailed survey of the present position with a full recording of the facts on maps, followed by an analysis of the results—

the identification of the role played by physical, historical, socio-economic and other factors.

The measurement of a country's land resources is a complex problem, and it is extremely difficult to give some qualitative assessment of different types of land or classes of soil. Measurement of actual output is somewhat easier, and Professor Stamp suggested a Standard Nutrition Unit, or SNU, of 1,000,000 calories farm output per annum. Allowing 10% loss in preparation, cooking and for seed, each unit represents 900,000 calories available for consumption, or 2460 calories per day—a reasonable world standard.

The use of SNU enables the "carrying capacity" of land in terms of food for human beings to be measured and compared. Some diets (meat and milk, for example) are very extravagant of land and may require as much as 3·5 acres to produce one unit, whereas a mainly wheat-bread diet may take only 0·25 acre, and under the very intensive rice culture with beans in Japan 6–7 units are produced per acre. In "carrying capacity" there is thus a range from at least 20 to 1.

At present the maximum population in terms of subsistence agriculture is found in the plains of Japan where 4000 people are actually supported on one square mile of land. But in the future the same food could doubtless be produced by fewer people, and the problem then becomes what to do with the surplus population. Competing demands on land are many and insistent. In every country the need for a planned use of land resources is becoming apparent; in many it is vital and urgent.

INDUSTRIAL AND TECHNOLOGICAL NEEDS

Sir Alexander Fleck, a past president of the Association, discussed the physical and chemical side of agricultural technology, confining his attention mainly to practical measures that could reasonably be undertaken within, say, the next ten years and would show some hope of giving a return on the capital employed.

Fertilizer Nitrogen

By far the most important problem is that of providing crops with adequate water and nutrients. Most crops are starved of the essential elements nitrogen, phosphorus and potassium, yet the world's deposits of phosphate and potash will suffice for a very long time to come, and supplies of nitrogen, which has to be fixed from the air, are unlimited. World production of fertilizer nitrogen has advanced by leaps and bounds and is now some 100 million tons per annum, but, said Sir Alexander, "the fixation of nitrogen still ranks as one of the most underexploited chemical discoveries of all time, having regard to its potentialities for promoting human well-being." Thus Japan, by applying fertilizer nitrogen at a rate of about 100 lb. to the acre, and by concomitant improvements in agricultural practices, achieves average yields from her paddy fields of about 35 cwt. per acre, whereas India, applying only 1 lb. per acre obtains little more than a quarter of this yield; yet local Indian yields have been multiplied two- or three-fold on experimental farms.

Calorie deficits ought to be made good with protein as well as carbohydrate food, but the efficiency of conversion of fertilizer nitrogen to animal protein is low and this adds to the amount of nitrogen required. For the world as a whole estimates of fertilizer nitrogen likely to be needed by the end of the present century range from over 30 to nearly 60 million tons a year.

Formidable but not impossible quantities of energy would be required. Some vast hydro-electric schemes like the Bhakra-Nangal project in India are coming into being, capable of producing energy on the scale demanded. Although it will be a decade or two before nuclear power makes an appreciable contribution in Asia, its long-term significance to a country like India, with plentiful supplies of thorium, is immense. In places like the Middle East and Venezuela natural gas that is now wasted could be collected and made into several million tons of fertilizer nitrogen, though the economic difficulties are considerable. In India some 225 million tons of cow dung that ought to be fed to the land are burnt as fuel annually.

Lack of water is all too often the principal factor limiting crop growth; but although irrigation has been practised for at least 4500 years, the equipment used has changed little during that time. There is a great need for the more efficient electric pump, which will take water from a deep tube-well and supply several hundred acres of land. In certain parts of Pakistan such equipment is badly needed also for land drainage and reclamation, where rise of the water table has brought salt to the surface. There is great scope for dam construction: the Kariba and Bhakra Dams, magnificent conceptions though they are, are only beginnings.

Other Technical Problems

Mechanization is certainly not an essential prelude to the solution of world food problems. The emphasis in Western agriculture is on greater output per man; the underdeveloped countries must concentrate on a higher yield per acre. No doubt it would be possible to flood Africa and Asia with tractors, but it would probably be of much more use to manufacture an improved bullock-drawn plough, or to replace the clumsy appliances now worked by hand with simple implements of sound design, light yet durable. "Much progress can be made in short steps, where big leaps lead to disaster," said Sir Alexander. "We should not easily forget the lesson of the groundnut scheme which gave birth to the aphorism 'Give us the job and we will finish the tools'." The lesson is not to thrust undiluted western techniques of mechanization on primitive smallholdings, but rather to help in evolving new and simple tools appropriate to the situation in which they will be used.

More effective use must be made of food supplies. Much food is lost because it can neither be promptly transported to where it is needed nor preserved without spoilage until it can be consumed. The whole of a plant is seldom eaten, though the part rejected may contain much nourishment in an inaccessible or unpalatable form. We use but a small fraction of the standing crop of the sea, yet it contains more vegetable matter than covers the land and enough fish to fulfil our protein requirements for years.

Avoidance of waste is often simply a matter of building a road; but speedy transport cannot solve the whole problem of perishable food and means of preservation must also be provided to smooth out irregularities in supply. For lack of deep-freezing plants, dehydrating plants, canning factories and so on, temporary gluts of valuable food go to waste in the midst of under-nourished peoples.

The destruction of food by disease, insects, weeds or vermin must be prevented. Most of the really effective weapons against such biological attack are chemical substances, and there is ample scope for the use of veterinary pharmaceuticals and plant protection products. The job of the technologist is to build serviceable plant for manufacturing these materials as cheaply as possible.

British scientists and technologists will be wanted to provide technical advice and training in field and factory at home and abroad. There are many schemes for technical aid, but most of them depend for their success on finding suitable individuals willing to work in underdeveloped parts of the world; enough qualified men must be found for these jobs. British technologists can assist indirectly by helping to develop machinery and materials capable of finding useful application in underfed territories. They should be prepared to co-operate even in technical problems not directly relevant or profitable to ourselves in Britain. We must be receptive and attentive to other peoples' technical problems and be willing to give them the benefit of our experience and our success. "This business of satisfying hunger throughout the world is about the biggest technical challenge of our times," said Sir Alexander. "It is also one which we must not fail to meet."

THE APPLICATION OF SCIENCE TO FOOD PRODUCTION

Dr. H. D. Kay, professor emeritus of the University of Reading, put the proposition forward that it is not shortage of scientific knowledge nor of methods for applying it to agriculture or dietetics that is the major obstacle to fairly speedy improvement of nutrition in most of the hungry countries. It is rather the extreme slowness of implementation of that knowledge, a slowness caused by political, sociological and psychological obstacles, to overcome which effective techniques have still to be found.

In the underdeveloped countries a net increase of population of above 2% per annum is not uncommon, and a net increase of over 3% (which would double the population in just over 20 years) is reported in a few of them, unaccompanied by any even remotely comparable increase in food production. The only feasible way for most of these countries to improve their diet is by increasing food production from their own acreage, and there is no doubt that large amounts of extra food—considerably more than 50%—could be produced by applying known methods. In parts of India and Africa a few thousand pounds spent on barbed wire, improved seeds, and fertilizers, could raise local production by hundreds per cent. Instances are to be found where good farmers, with little capital, have doubled or tripled their output of food crops by using modern methods. But the practical agricultural and livestock problems can be met only if science is effectively applied. That is, (i) if competent advisers are available to disseminate the knowledge, (ii) if farmers are able and willing to make use of it, (iii) if financial resources permit and (iv) if the social resources of the country provide sufficient incentives.

What are the real obstacles that prevent so many countries from going ahead? One is lack of indigenous drive: governments are not yet convinced that they have duties other than the preservation of law and order; instability of government may also be a cause. Another is that population changes have been so rapid that governments do not realize that the adequate feeding of the now expanding population has become a national objective of over-riding importance, and one that is attainable if they set about it.

Once a government has been convinced that something must be done about better feeding, the early visit of an expert group to survey existing conditions, and to make concrete recommendations, can be of the greatest assistance. As a result, workable proposals can usually be put before a government as to methods for substantial improvement in the food chain and suggestions made as to the type of technical education and economic help that may be needed from without. Surveys by F.A.O. and U.N.I.C.E.F. teams have frequently done much to raise nutritional and living standards in various districts.

In many countries what is required is not so much the more intensive cultivation of cereals or root crops as a husbandry that will raise soil organic matter, improve soil fertility, prevent erosion and convert wastes from arable crops via livestock into protein-rich food. More crops could be obtained from smaller acreages as a result of the improved fertility. Animal production can, however, become a menace, as in India, where cattle have religious significance. A very substantial reduction in the enormous, unproductive, grossly-underfed cattle population in India would lead to far greater supplies of milk; but the slaughter of cattle is prohibited on religious grounds.

There is much need to lessen the psychological and social handicaps that harass the hungry countries. Notable among these is an acute shortage of technical personnel; yet this could be remedied within three or four years by co-operation with the technically developed countries.

CONCLUSION

The papers submitted at this colloquim, said Professor P. M. S. Blackett in the final address, have provided just those facts and inferences needed for a realistic approach to the outstanding world problem of Food and Population. By the end of two decades or so it will be possible for a world organization to discuss usefully what can be done by 2000 A.D. Now is a time for action. By entirely understandable steps, the scientific industrial revolution has multiplied by ten or more the material wealth of about a quarter of the world's population and hugely increased the production of food. The other three-quarters are setting out on the same road: they are in a hurry. They need help and they will get it.

One of the most important tasks, he believed, is to acquire a sympathetic understanding of the problems and difficulties of the emergent nations. To help them to acquire the skills they need, he hoped universities, colleges and training establishments in the United Kingdom will markedly increase the number of places made available for students from the emergent countries, and loan staff to states in need of help. Further, industrial and commercial firms operating in these countries should increase their training facilities for African and Asian personnel.

At the research level he hoped the British Government will make generous arrangements for the maintenance and enlargement of research stations in our former colonies. Strong support should be given to the setting up of regional international institutions for research and development. Industry should devote more attention to the development of products needed by the emergent nations.

"I am convinced," concluded Professor Blackett, "that the existing level of scientific technology is, in the main, amply sufficient to allow the solution of the world's food problem over the next few decades by the wide application of known methods. Scientific and technological advances will come and should be welcomed as windfall profits, but should not be planned for. We as scientists and technologists have already given ourselves the tools by means of which hunger could be banished from the world—it is now up to us as citizens of the world to make sure they are used, so as to finish the job."

INCREASING WORLD FOOD SUPPLIES THROUGH GREATER CROP PRODUCTION

H. L. Richardson

(*Imperial Chemical Industries Ltd., Billingham Division, London*)

By the intelligent and widespread use of fertilizers along with other improvements in farming methods, food production in the underdeveloped countries could be expanded for a long time to come at a faster rate than that at which populations are likely to rise. No new discoveries are required, but governments must be prepared to spend much money and effort on development work, particularly in the provision of adequate advisory services.

Much has already been said and written on the population and food problems of the world, and the part that agriculture can play has been exhaustively reviewed by Sir John Russell in his book, *World Population and World Food Supplies* [22]. A fresh impetus has now been provided by the United Nations Freedom from Hunger Campaign, launched in July 1960 and due to be continued for five years. In Britain attention has been focused on the matter by conferences and publications related to this campaign [23], and more notably by the Symposium on World Food and Population held by the British Association at Cardiff in September 1960. A number of very distinguished speakers contributed to this Symposium, and in addition papers related to the general subject were delivered to various Sections of the British Association.

One of these sectional papers was given by the writer [21]. Its title was "What fertilizers could do to increase world food production," and the purpose here is to develop this theme in more detail and with fuller documentation than was possible in a popular talk.

At the outset it should be made clear that in emphasizing the value of fertilizers the author by no means undervalues the many other factors that are important in increasing crop production. It is obvious that good crops cannot be grown without adequate moisture supplies; that selected and tested new varieties will give better yields than the old ones (Figures 1–3); that improvements in cultural methods and in the succession of crops will make still higher yields possible; and that crops have to be protected from weeds, pests and diseases. These and other factors are just as important as the use of chemical fertilizers, sometimes more important. It will be assumed that the fertilizers are being used correctly, so as to maintain or increase the fertility of the soil [16]: this will frequently involve also the application of local organic manures or the growing of grassland leys or leguminous forage and cover crops.

This study will be based in the first place on the results of field experiments and trials. These experiments have generally, and rightly, been carried out using current methods of farming and crop varieties; thus they relate to present conditions in the countries concerned. But the responses obtained cannot be taken in isolation, especially in considering the future, for in any country that is busy improving its agriculture other aspects of better farming will inevitably be coming into play while fertilizer use is being introduced or increased, and account must be taken of the interactions.

Rate of application of plant nutrients is of the first importance. Heavier applications can give bigger yield increases than low ones, up to a point; but they require more skill and knowledge on the part of the farmers, as well as better farming techniques generally, if they are to be safe and effective. For this reason fertilizer experiments in underdeveloped countries are often carried out using rates of application that seem low by modern standards. The responses may appear small, and indeed they are only a partial measure of what can be obtained. They show the degree of crop increase that can be expected at the present rather primitive levels of farming; but as techniques improve heavier applications will become practicable and secure greater returns.

Allowances will be made for the foregoing considerations when estimating what fertilizers could do in the future. Frequently these can be based on the results of past experiments relating to a range of rates of nutrient application or to the combined effects of fertilizers and other factors, such as better irrigation or improved varieties. This is much better than guesswork. None the less it is clear that any estimates of this kind must be highly empirical, making many unexpressed assumptions. It is usual, for example, to look ahead for only a limited period—say one human generation—and to envisage a slow rate of improvement in farming methods; but over longer periods and assuming greater developments, crop yields could justifiably be forecast for considerable areas of the earth's surface, which today might seem unrealistically high.

Another line of approach is to study what fertilizers have achieved in countries that already use them extensively. This provides a check on assumptions made in the study of field experiment results and, as will be shown, confirms that the conclusions reached by the author are by no means exaggerated.

FIELD EXPERIMENT RESULTS IN INDIVIDUAL COUNTRIES

It would seem simple to determine fertilizer potentialities from the responses given in past experiments, but many difficulties arise in relating such results to future possibilities. Some of the problems involved have already been mentioned; others relate to such questions as whether the experiments and trials were in fact representative of the farming in the country being considered: were they soundly designed, were there enough of them, were they well placed on ordinary farms as well as experimental stations, and so on. Such problems have been discussed elsewhere [19], and here are considered only the effects of fertilizers in a few of the underdeveloped countries having experimental programmes that are satisfactory from this point of view. China and India are selected because they represent the two greatest population masses in the world, and their food problems are pressing; Ghana is chosen as a tropical country representative of a wide belt of Africa; Mexico typifies in many respects—although only partly in climate—a wide belt of countries in central and south America.

The crops selected for study are mainly the cereals that contribute most to the domestic food supplies in each country. Other crops and grassland, of course, also provide important parts of the diet, but in the underdeveloped countries these usually give even larger responses to needed fertilizers than do the cereals; hence their omission can only underline the moderation of the general conclusions. Economic crops have also had to be left out of consideration, although some of them, like sugar cane, make a useful contribution to the food supply; many of them are already well fertilized, even in underdeveloped countries.

POSSIBILITIES IN CHINA

Rice

Before and during the last war large programmes of co-operative fertilizer field experiments were carried out in China by I.C.I. (China) Ltd. and by national and provincial governments and universities. Some of the general results with various crops have been summarized by the writer [17], who has also made a detailed study of those obtained with paddy rice [18].

The response of rice to fertilizers of course varied greatly with the soil type, the use of local manures and other factors, but the averages from nearly 300 replicated experiments can be taken as fairly representative of conditions in the rice-growing region. These show that treatment with 54 lb./acre of N, P_2O_5 and K_2O increased the yield per acre by 755 lb. of paddy or rough rice over the yield without fertilizer of 2100 lb.—an average response of 36%.

Still greater increases can be obtained. The standard application of nitrogen in the above experiments, namely 54 lb./acre, is low in comparison with the average of 80 lb. actually used by rice farmers in Japan and Taiwan. By using data from fertilizer response curves in the Chinese experiments it can be calculated that if the Chinese farmers were to apply chemical nitrogen at the 80 lb. rate, in addition to phosphate and potash at the standard rates and the traditional local manures, the crop would be increased by some 46%, raising the yield per acre in mainland China from its level of 2330 lb.* in 1955–57 to 3400 lb.

Further responses would be secured as other improvements in agricultural techniques were introduced. Modest estimates, based on experience in China and Japan, would be: improved varieties (including interaction with fertilizers) 15%; better cultural methods and water control (including interaction with fertilizers) 15%; and pest and disease control 10%; giving a total of 40%. The combined increase attributable to all improvements would be 86%, raising the yield of paddy rice per acre by 2000 lb. to about 4300 lb. This figure is almost the same as that actually achieved in Japan in 1955, suggesting that the assumptions made are reasonable. It is not, however, set as the upper limit for China. Individual farmers or districts having especially favourable soil and water conditions are likely to get rice yields far higher than 4000 lb./acre; but inefficient farmers or those farming poor soils or having unreliable water supplies are bound to get lower yields.

---

* Unless otherwise stated, national average crop yield figures are taken from F.A.O. Production Yearbooks, or recent official sources.

Wheat

In the Chinese fertilizer experiments with wheat the response to fertilizers was similar on a percentage basis to that with rice, though the quantities harvested from both manured and unmanured land were much lower. In most of China wheat is grown as a winter crop and harvested in the spring, and the cold dry winters restrict growth of the crop and limit the response to fertilizers.

In some 140 replicated experiments on wheat the average response to treatment with 54 lb./acre of N, P_2O_5 and K_2O was 460 lb. of grain—an increase of 41 % over the 1120 lb. produced on the unmanured controls. In mainland China in 1955–7 the average yield was 780 lb. per acre: 41 % of this is 320 lb. If, as with rice, another 40 % is added for the effects of accompanying improvements, the combined increase would be 630 lb. giving a crop per acre of 1410 lb. With nitrogen applied at the 80 lb. rate the combined increase would be 89 % and 1500 lb. would be harvested. This is still a very modest figure by world standards: Japan's average for 1955–7 was 1920 lb., and far higher yields are obtained in western Europe, where the crop has a longer growing period.

The first need of wheat in many parts of north China is irrigation, and not until this is supplied are higher initial yields and larger fertilizer responses likely to be obtained. Experience in Mexico, mentioned later, has shown that the yield of irrigated wheat on long-cultivated soils can be multiplied several times by fertilizer use.

Summer Grains

The summer dry-land cereals (excluding rice), namely the millets, sorghum and maize, are important sources of food in northern and western China. Because they are grown during the moist monsoon summer, their average yields are much higher than that of wheat; they also respond well to fertilizers.

Fewer experiments were done on the summer dry-land cereals than on rice or wheat, but collective results showed that treatment with the major elements at 54 lb./acre gave 755 lb. over the unfertilized yield of 1800 lb./acre—a direct response to fertilizers of 42 %. With the allowance for other agricultural improvements as made for rice and wheat, yields would be raised by 80 % over the present average; and if in the course of time nitrogen came to be applied at 80 lb./acre, the combined increase would be enough almost to double the crops now obtained.

POSSIBILITIES IN INDIA

Rice

Many fertilizer field experiments on rice have been done in the past in India, by I.C.I. (India) as well as by official bodies, and simple field trials have been and are being carried out on a very large scale. The results of the earlier work, summarized by Yates, Finney and Panse [28], showed an average response of 280 lb. of paddy rice from 20 lb. of fertilizer nitrogen, this being 18 % over the average unfertilized yield. These figures seem small, but the rate of application was low compared with those so far discussed. In these experiments phosphate at 20 lb. P_2O_5/acre gave an average of 132 lb. of rice, or 7 % of the no-phosphate yield (which was higher than the no-nitrogen yield). A recent review by Abraham [1] of the results of tens of thousands of trials in cultivators' fields showed an average response of 304 lb. of paddy rice to 30 lb. N/acre, and of 230 lb. to 30 lb. P_2O_5/acre. The unfertilized yields were not stated in connection with these results, but taking as a basis India's average yield per acre of 1140 lb. of paddy rice—only a small proportion of which is manured—the responses would be 27 % for nitrogen and 20 % for phosphate. Larger responses have been reported by Tamhane [26], also on a basis of numerous trials in cultivators' fields throughout India; the increase per acre from 30 lb. N was 514 lb. of grain, and that from 30 lb. P_2O_5 was 275 lb. Potash fertilizers were not included in the main series of trials because earlier work had shown that few Indian paddy soils respond to the element.

A combination of these and some other results shows that, on an average per acre, 30 lb. N gives 370 lb. of paddy rice and 30 lb. P_2O_5 gives 220 lb., making a total from the two of 590 lb. This is 52 % of India's present yield of 1140 lb., so that fertilizer treatment at these moderate rates would raise the crop to 1730 lb./acre.

Some allowance can be made for the effects of concomitant improvements, and because standards of farming are poorer in India than in China these are likely to have a greater relative effect: very modest estimates would be a 20 % increase attributable to new varieties and their interactions with fertilizers, 20 % for better cultivation and water control, and 10% for pest and disease control, giving a 50% increase apart from the direct effect of fertilizers. The combined effect would be enough to give India an average of 2300 lb. of paddy rice to the acre—double the current yield.

This figure appears to be one that could be realized within a generation. The chief problem will be that of extension and advisory work: persuading the Indian cultivators to adopt the new methods. Something like 1 million tons of fertilizer nitrogen would be required to apply an average of 30 lb./acre to the rice fields of India, but the Indian Government is already planning the installation of new nitrogen plants on this scale.

In point of fact, the yield of 2300 lb. to the acre is still a low one for paddy rice. Malaya, which has increased its rice production considerably in the last two decades, is already close to that figure; Taiwan is well past it; Japan is approaching a yield twice as great. It might not seem reasonable to expect a country as large as India, with its wide variation in soils and climates, to achieve as high an average yield as a smaller country like Japan; yet Japan also has climatic extremes and soils where rice once grew poorly.

The low rate of 30 lb. for N and P_2O_5 used in the recent Indian trials was chosen deliberately, because most Indian varieties of rice cannot make use of heavier applications of nitrogen, which may cause lodging or intensify disease attack. A vigorous search is going on, in India and elsewhere, for new varieties that can be grown in the tropics and use heavy dressings. This work is bound to succeed—such rice is already grown in Taiwan—and when these varieties become widely adopted along with improvements in cultural methods that are currently in progress, it will be entirely reasonable to consider using fertilizers at much heavier rates. Use of these varieties with nitrogen at 80 lb./acre and phosphate where needed should increase the present yield per acre by about 90%. If to this is added 50% for the other agricultural developments, the combined effect would be to raise current yields by 140%, giving 2700 lb. of paddy rice to the acre.

Others have said that rice yields in India might eventually be raised to the present Japanese level, but taking into account the difficulty experienced in Taiwan in reaching this standard, despite heavy fertilizer use—due in part to the growing of two or three short-period crops in the tropics instead of one long-period one—an average of around 3000 lb./acre is a reasonable long-term target in India. Although this is only about three-fourths of the Japanese yield, it is nearly three times that now produced in India, and it may require more than a generation of general improvement in farming techniques for its attainment.

There is certainly no climatic barrier to obtaining high rice yields in India. In government-sponsored competitions among farmers for the honour of growing the highest yields, figures of from 8400 to 11,200 lb. of paddy rice per acre have been recorded. Doubtless the prizewinning fields had exceptionally fertile soils and received heavy manuring, but the point is that—even with existing varieties—it was possible to obtain such yields under Indian climatic conditions. Russell [22] also has drawn attention to rice yields of 4000 lb. or more having been obtained in India, and to experimental farms commonly obtaining yields well above the average.

Wheat

As in China and other parts of the Far East, wheat is grown in India as a winter crop harvested in the spring. Because of the monsoonal type of climate the winters are dry as well as cold, and this limits yields and the possibilities of increasing them by applying fertilizers, unless the crop can be irrigated. The average yield of wheat per acre in India in recent years was only 660 lb. as against 1920 lb. in Japan and far more in western Europe.

Most of the fertilizer experiments and trials on wheat were done on the irrigated crop. The effect of irrigation on the response to nitrogen can be seen in a small number of experiments reported by Yates, Finney and Panse, in which 20 lb. N/acre gave 230 lb. with irrigation but only 140 lb. without it. In the large series of experiments recently reported by Abraham only irrigated wheat was included, and the response per acre to 30 lb. N was 263 lb.; the response to 30 lb. P_2O_5 was 198 lb. and in other trials 30 lb. N + 15 lb. P_2O_5 gave 296 lb. Although these responses with irrigated wheat were rather less than those obtained with paddy rice, it is clear that where fertilizers can be combined with irrigation there are good prospects for increasing wheat yields in India.

Bringing together all the results available gives a response per acre on irrigated land of 432 lb. to the application of 30 lb. N + 30 lb. P_2O_5 where needed. No figure is available for the average yield of wheat on irrigated land in India, but it would be substantially above the national average of 660 lb.—perhaps around 1000 lb. On this basis

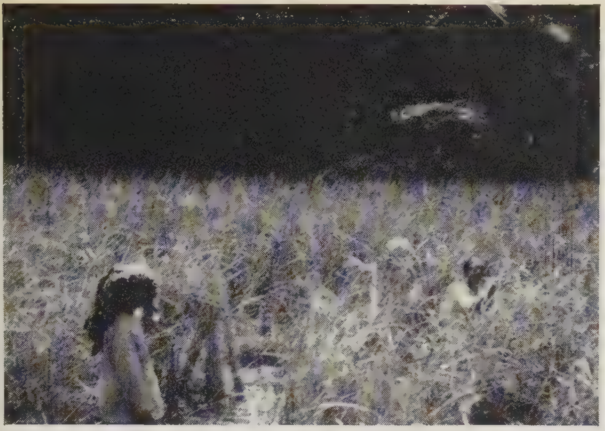

FIG. 1. Malaya. Harvesting an unimproved variety of rice. (Long-stemmed, easily lodged, relatively low grain yield, limited response to fertilizers.)

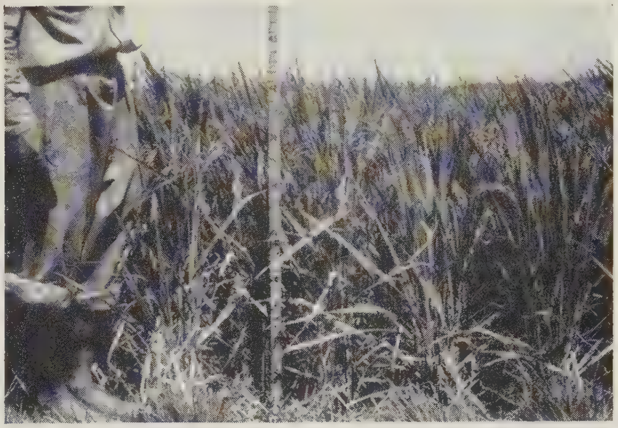

FIG. 2. Malaya. An improved rice selection. (Short-stemmed, resistant to lodging, heavy grain yield when well fertilized.)

an increase of about 45% in the production of irrigated wheat would be secured by using fertilizers at 30 lb. of nutrient per acre, under existing agricultural conditions.

As farming techniques improve and heavier dressings become practicable, average yields of the order of 2000 lb. might reasonably be expected on irrigated land. At the present time, however, only about one-fourth of the wheat acreage is irrigated and, although irrigation by canals and by tube wells is being actively developed under the various Five Year Plans, not all the wheat is grown in places where irrigation is practicable. If it is assumed that half of the wheat land will eventually be irrigated and that this and the unirrigated half are improved in other ways, a national average of 1500 lb. should be attainable. This is still a low figure by world standards, and well below the wheat yield currently secured in Japan.

Summer Grains

Little experimental work with the summer dry-land cereals (millets, sorghum and maize) has been reported from India, although they are important sources of food in the centre, north and north-west. The writer has himself observed the thin, stunted, and nutrient-deficient appearance of these crops in India, and it is to be expected that adequate manuring would secure large increases in yield, except during occasional drought years. By analogy with the results for the same crops reported above from China, and with the conclusions already given for rice and wheat in India, it is likely that the yields could be at least doubled by good treatment.

POSSIBILITIES IN GHANA

Guinea Corn and Millet

The results of a comprehensive series of fertilizer field experiments in the Gold Coast (now Ghana) have been reported by Nye [12] and Stephens [25]. Both replicated experiments at research stations and many hundreds of unreplicated trials on ordinary African farms were included, so that the results are widely representative. The findings were naturally complex, varying with kind of soil, previous land use, and so on; but it will suffice to take simple averages of the results

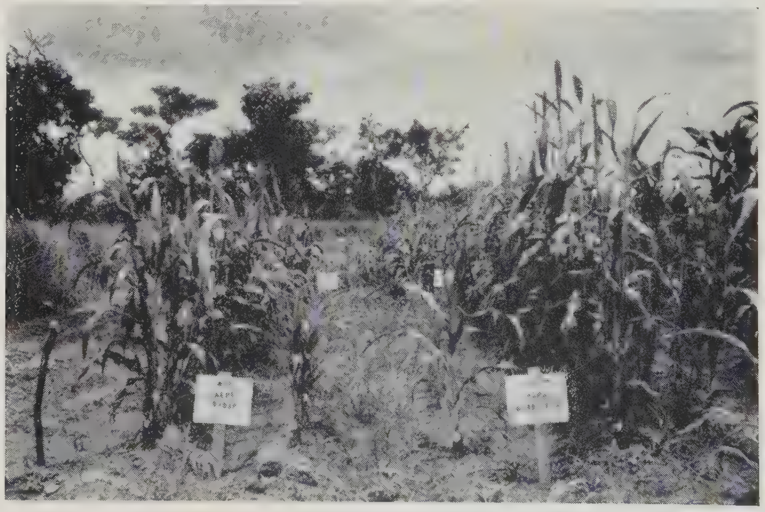

FIG. 3. Ghana. A combined variety and fertilizer trial with sorghum. Left-hand and right-hand pairs of rows are two different varieties; inner two rows, unfertilized; outer two rows, fertilized with NP.

reported for all areas, the figures quoted here representing the sum of the responses to nitrogen and phosphate (potash being generally omitted because ineffective) applied at 25 lb. N and 22 lb. P_2O_5 per acre.

Guinea corn and millet, grown either separately or together, are typical crops of the savannah belt of central and northern Ghana. The average response per acre of the two crops to both nitrogen and phosphate at the rates mentioned was 486 lb., this being a 68% increase over the unfertilized yield of 714 lb. (Figure 3). The yield of the unmanured crop was very low, so that a fairly high percentage response does not represent a great increase in pounds of grain per acre.

It may again be assumed that better farming methods would add at least 50% to the direct effect of fertilizers, raising the yield level to 1560 lb. Further, the low rates of application used in these trials were adapted to the primitive farming methods of the African cultivators, and far heavier rates are likely to prove practicable as farmers become more experienced and farming methods improve. Doubling the experimental rates would probably double the unfertilized yield and with the allowance for the other improvements give a crop of around 1800 lb./acre—not an unduly high figure for millets and sorghum by the standard of agriculturally more developed countries.

Support for the foregoing estimates is to be found in a continuous manurial experiment at Samaru, Northern Nigeria (where conditions are very similar to those in central and northern Ghana): the average yields of guinea corn on plots receiving both nitrogen and phosphate at rates of only 21 and 18 lb. per acre respectively were close to 1500 lb./acre; some of these plots also received a little farmyard manure [13] (Figure 4). It is a matter of common observation in Ghana, as in other underdeveloped parts of the world, that crops like guinea corn are extremely thin and poor in unmanured fields, but that tall, dark-green patches yielding several times as heavily occur either near villages or on abandoned hut sites (Figures 5, 6, 8). These fertile patches in themselves illustrate what could be achieved by manuring and fertilizer use, despite any climatic limitations that may occur locally.

Maize and Other Food Crops

Maize in Ghana is grown mainly in the forest and savannah woodland zones. The earlier fertilizer experiments on this crop suffered severely from attacks of maize rust but results given b Stephens [25] for all areas growing maize, unmix with guinea corn, show an average response t 12·5 lb. N + 11 lb. P_2O_5/acre of 137 lb. maize, this being 21% over the unfertilized yield of 648 lb. At double this application, as used for the experiments on guinea corn and millet, the response would have been about 30%. This relatively low effectiveness of fertilizers for maize, compared with guinea corn and millet, may have been due partly to soil differences, but the maize-rust attack reduced both yields and fertilizer responses. Stephens remarked that closer planting of the maize and improved varieties would make fertilizer use more attractive.

Groundnuts are a major crop in the savannah zone of central and northern Ghana, and although they are largely grown for export they also contribute to local food supplies. In the experiments reported by Stephens, the average response of groundnuts in all areas to single superphosphate at 22 lb. P_2O_5/acre was 286 lb. of kernels, or 58% of the unfertilized yield of 495 lb. Thus, on a percentage basis, fertilizer was as effective with groundnuts as with guinea corn and millet. Triple superphosphate supplying the same amount of P_2O_5 per acre was less effective, indicating that there was a response to the sulphate in the single superphosphate.

Root crops—principally yams and cassava—are important sources of food in the southern savannah and forest zones of Ghana. Both these crops responded well to fertilizers (Figure 7), although the percentage increase with yams was not so great as with most other food crops, probably because the yams were usually planted on relatively fertile soils. For yams in the central savannah and savannah woodland zones the response to 25 lb. N + 22 lb. P_2O_5/acre was 1432 lb. of tubers, this being 23% of the unmanured yield of 6109 lb. For cassava in the Accra Plains, nitrogen and phosphate at the above rates plus 36 lb. K_2O gave a response of 5893 lb. of tubers per acre or 77% more than the unmanured yield of 7654 lb. Large responses have also been obtained in the savannah woodland zone and it is clear that fertilizers can do a great deal to increase food production with this crop. The average gain for both yams and cassava was just 50% at the rates employed.

POSSIBILITIES IN MEXICO

Wheat

Since the last war an intensive programme of agricultural development has been carried out in

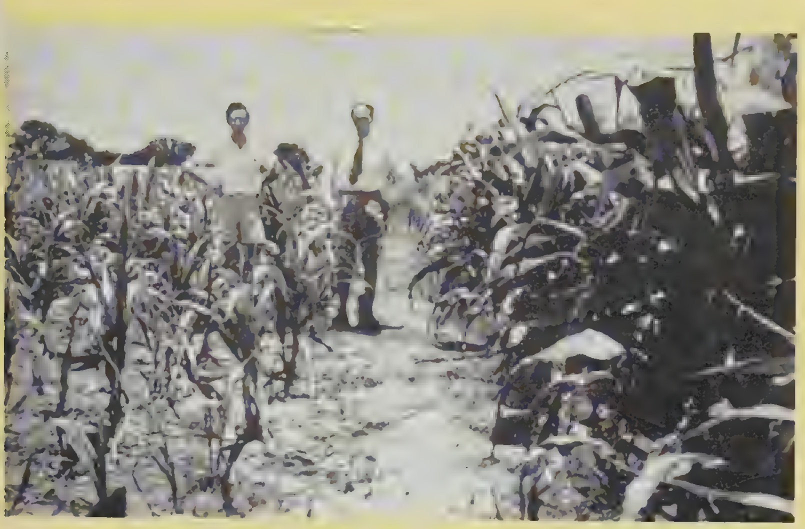

FIG. 4. Nigeria. A continuous manurial experiment with sorghum. In left foreground, no phosphate; in right foreground, NPK and dung.

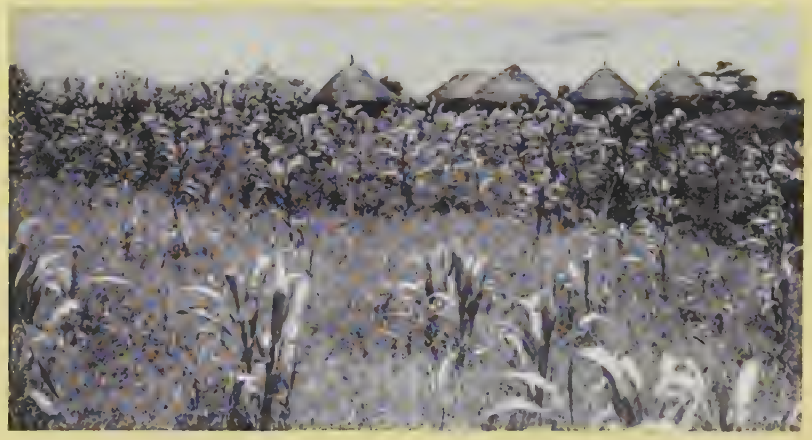

FIG. 5. Nigeria. A poor and weedy crop of sorghum, except near the hut compound, where the crop has benefited from household and human refuse.

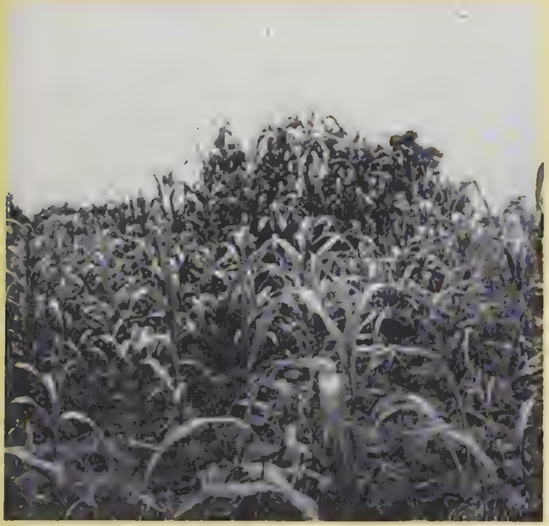

FIG. 6. Nigeria. A nutrient-starved crop of sorghum. The good patch at the rear is growing on a fertile spot, perhaps an old hut site, indicating what manuring can do to improve the yield.

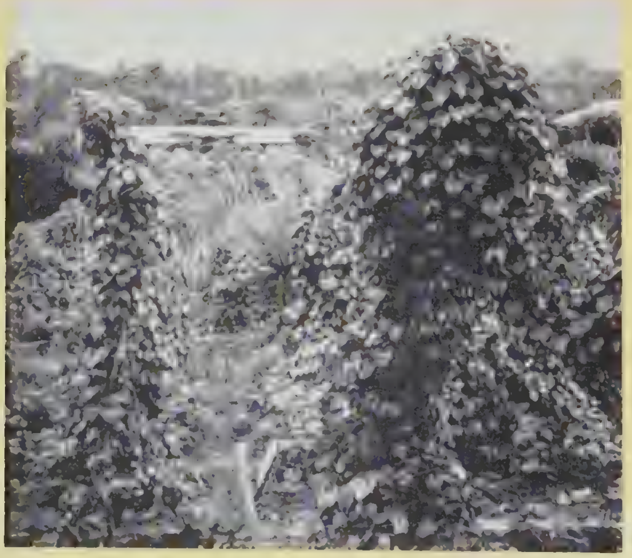

FIG. 7. Nigeria. A fertilizer experiment with yams: left-hand vine, no fertilizer; right-hand vine, complete NPK fertilizer.

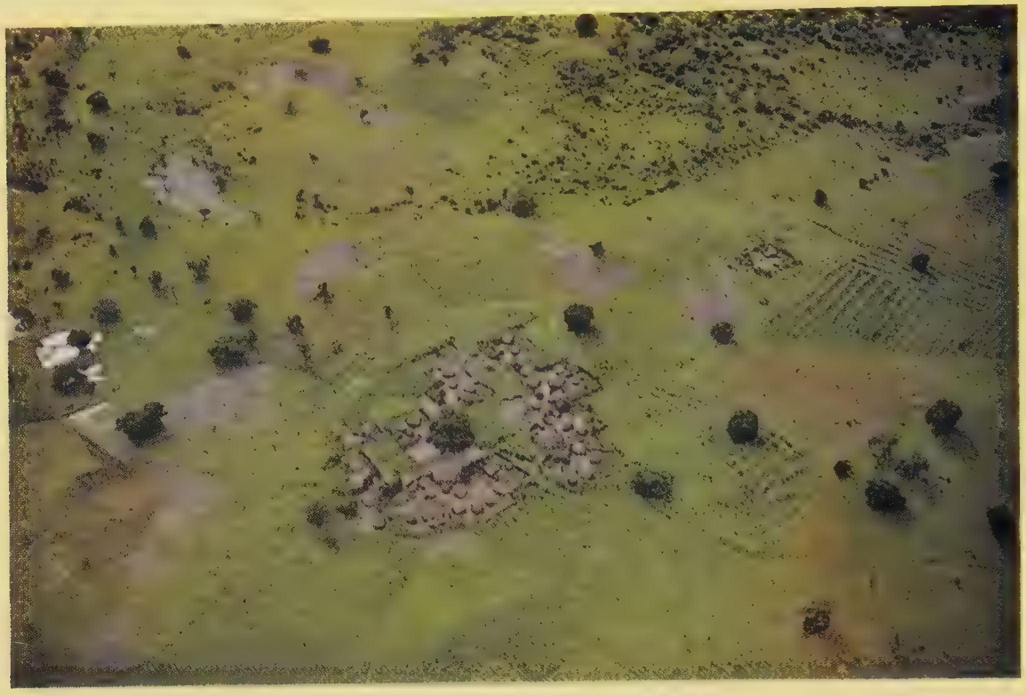

FIG. 8. Nigeria. Air view of a farm compound. Note how the crops are denser and darker green near the compound but thinner and paler (more nutrient-deficient) further away. Land use is extensive and unimproved.

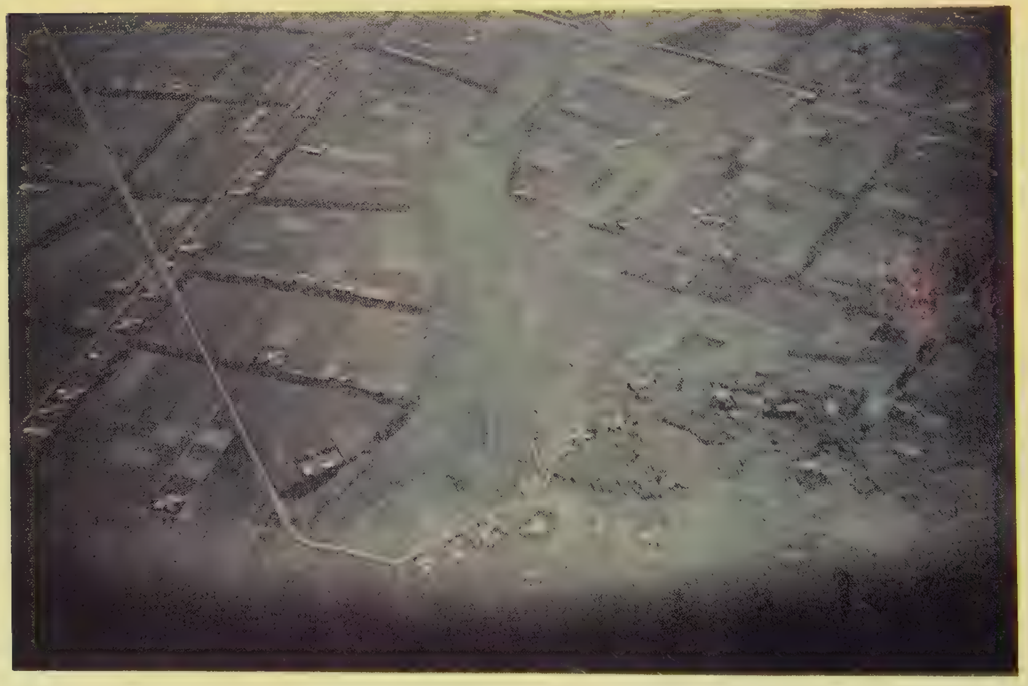

FIG. 9. Japan. Air view of the cultivated plain near Tokyo, showing continuous paddy rice near the centre and mixed rotation cropping, including dry-land rice, on surrounding areas. Note the intensive land use and dark-green, fertile colour of crops, by contrast with Figure 8.

Mexico, through co-operation between the Mexican Ministry of Agriculture and the Rockefeller Foundation. Full particulars are not available in publications having a general circulation, but there are reviews in Spanish [9, 10], while accounts in English of achievements with the wheat crop are given by Borlaug [2] and by Ramon and Laird [15]. In the course of the agricultural development work many hundreds of field trials have been carried out, the agricultural extension services have been greatly strengthened, chemical fertilizer consumption has multiplied many times, and crop production is increasing steadily. Overall results of the field experiments with individual crops are not available for comparison with those in the other countries reviewed here, but large increases were obtained by the use of fertilizers on good varieties that were resistant to disease.

Wheat is grown as an irrigated winter crop on the central plateau. Borlaug [2] drew attention to the increase in Mexican production from 400,000 tons in 1945 to 1,200,000 tons in 1957: this is attributable in part to an extension in area from 1·25 to 2·10 million acres during this period, but even more to an increase in yields due mainly to the use of improved varieties and chemical fertilizers. The first ten years of the development programme were largely devoted to field experiments and had little impact on the farmers; it was only with the subsequent growth of the extension services that the wheat farmers began to appreciate what fertilizers could do, and since then further development has been very rapid. By 1957 farmers who a few years before had never used fertilizer were already applying up to 120 lb. fertilizer N per acre to their wheat crop, and were benefiting accordingly. Borlaug states: "Some farmers are now harvesting 3–4 tons per hectare (45–60 bushels per acre) on the same land that yielded 400–700 kilos per hectare (6–10 bushels per acre) only four years ago."

What has been happening is also evident from the results of a complex experiment reported by Ramon and Laird [15]. This was located on deep alluvial soil which, like other long-cultivated Mexican soils, was deficient in available nitrogen; the wheat crop was irrigated, varying the supply of water from low to high; fertilizer nitrogen treatments ranged from nil to 135 lb./acre. There was an almost linear response to nitrogen up to 90 lb./acre at any irrigation level, but some flattening of response curves occurred at 135 lb./acre, although with optimum moisture supply the nitrogen response was still almost linear at this high rate. There were also some large interactions between moisture supply and the response to nitrogen.

The results as far as grain yields are concerned show that, with the driest soil moisture treatment (lowest irrigation level), yields in pounds per acre were 582 without nitrogen fertilizer and 2154 with 135 lb. N/acre; with optimum soil moisture treatment the corresponding yield figures were 612 and 3990. In other words, better irrigation without nitrogen increased the yield by a mere 5%; heavy fertilizing with nitrogen multiplied the yield nearly fourfold, even with a deficient moisture supply, but more than sixfold with optimum irrigation.

These experiments have taught Mexican farmers how plant nutrients, effective in themselves, become still more effective as growth conditions are improved, and farmers are rapidly increasing their usage of fertilizers. The yield of wheat per acre in Mexico has almost doubled since the war, having risen from 732 lb. in 1946 to 1401 lb. in 1958, and most of this increase has taken place since 1952. This achievement—and, of course, the rise in overall output—is an excellent example of how rapidly food production can be increased, even in an agriculturally underdeveloped country, if a really adequate campaign of field experiments and extension work is put into effect. In the absence of full experimental results a fair estimate of the long-term possibilities of using chemical fertilizers on wheat cannot be made, but even if the average response to nitrogen were only a half of that recorded in the experiment quoted above, it should be possible before very long to treble the early post-war yield per acre.

Maize

Although such striking results have been obtained with wheat (grown in winter), maize (grown in summer) remains the most important food crop The author has not seen any results of experimental work with maize to compare with that on wheat, but improvement of the crop is likely to offer more difficulty. For one thing, maize is not generally irrigated but most of it has to depend on the rainfall, which may be sparse or erratic; for another thing, much of the crop is produced by primitive farmers in the hills who are less efficient than the wheat growers, accustomed to farming irrigated land in the plains. It will therefore be more difficult to carry out field experiments among the maize farmers, and harder to persuade them to adopt new methods.

De Lara [10] has shown photographs of very striking fertilizer responses with maize, but he has pointed out that in much of Mexico crop production is severely limited by high altitude or low rainfall. He stated that 400 fertilizer experiments with maize were done from 1944 to 1953, and that these have been used to provide advisory material for farmers. The maize farmers have begun to use fertilizers, and the practice is sure to spread. Although there has not yet been such a dramatic rise in maize yields per acre as in wheat yields, there are signs of an increase which can be expected to continue. The average yield per acre in the two years 1946–7 was 664 lb., whereas that in 1957–8 was 732 lb. and an estimate for 1959 is 760 lb. If Mexico can achieve only a half of the corresponding U.S.A. figure (2890 lb. in 1959), the present average yield will be doubled.

WHAT FERTILIZERS HAVE DONE TO INCREASE CROP YIELDS

Enough has been said to indicate the possibilities of fertilizer use, on a basis of the results of field experiments in underdeveloped countries, and the problem may now be approached from the opposite point of view, examining what two highly developed countries have succeeded in doing to raise yields with the help of fertilizers. It may not be possible to say exactly what proportion of the general yield increase can be attributed to the direct effects of fertilizers, yet a reasonable estimate can be made; it is certain that the proportion is large and that without fertilizers such high levels of production could not have been achieved.

For this purpose we shall take the history of wheat fields in England and of rice yields in Japan. In both countries yield records are available which go back to medieval times, when methods of farming and yields per acre were comparable with those in many underdeveloped countries today. The subsequent trend of yields gives an indication of what the less advanced countries can hope to achieve, and the improvement will of course take place at a far more rapid rate with the application of modern advisory and technical methods.

Wheat in England

Past and recent average wheat yields in England (or the U.K.) are given in Table I; the early figures were quoted by Sir William Gavin [5]. Here and elsewhere, yield values have been transposed into pounds per acre for ease of comparison with other crops: yields expressed in bushels are misleading, because bushel weights vary with different crops.

TABLE I

WHEAT YIELDS IN ENGLAND

Period (A.D.)	*c.* 1250	*c.* 1350	*c.* 1550	*c.* 1750	*c.* 1850	1900	1950	1959
lb./acre	380	500	940	1260	1640	1890	2350	3200

The low yields of the thirteenth and fourteenth centuries were those of the medieval open-field system, and are comparable with the yields obtained by the most primitive methods of shifting cultivation in underdeveloped countries today. By the sixteenth century there had already been some improvement in cultural methods, and perhaps more use was made of farm manure; the yields of wheat then being obtained in England were rather higher than the average in India, Pakistan or mainland China in recent years. With the coming of the enclosures and of better crop rotations, yields continued to rise, and the figure for 1850 of over 1600 lb./acre represents what could be obtained by good traditional farming methods, including the use of farmyard manure but practically no chemical fertilizers.

Since then, with still further improvement in varieties, with better control of weeds and diseases, and with the coming of the use of chemical fertilizers, the rise in yield has continued: in 1950 it was about 50%, and in 1959 about 95%, above that attained in 1850. 1959 was perhaps an exceptionally good year for wheat, but the 3-year average for 1957–9 was 2930 lb., which was nearly 80% above the level of 1850. English farmers still have quite a long way to go in the use of fertilizers on wheat; many of them are just beginning to realize how effective nitrogen can be on the new varieties which resist lodging; as Halliday has shown [7], large yield increases are still possible with cereals in England by using heavier dressings than the average farmer applies. It should not be more than a few years before the average yield is at least twice what it was in 1850, with values around 3300 lb. (For comparison, the average yield of wheat in Holland, where the crop receives almost all the fertilizer it can use effectively, is about 3500 lb./acre.)

Broadly speaking, the medieval wheat yield in England was more than doubled by the introduction of good traditional farming methods, including crop rotations and farmyard manure, and that yield in turn has very nearly been doubled again by the use of chemical fertilizers along with other modern methods. It would seem reasonable to attribute at least half of the latter increase to the effect of the fertilizers. Direct fertilizer responses varying around 50% were generally found in the field experiments in the underdeveloped countries reviewed, and a similar response is commonly observed in experiments with cereals in England even today.

Rice in Japan

The average yields of paddy rice (rice in the husk) in Japan, expressed in lb./acre, are shown in Table II, the earlier values being mentioned by Matsuo [11]. Each of the years 1957, 1958 and 1959 has seen a small increase in average yield over the year before.

TABLE II

RICE YIELDS IN JAPAN

Period (A.D.)	8th cent.	16th cent.	1883–7	1898–1902	1918–22	1938–42	1948–52	1959
lb./acre	1130	1690	2190	2540	3200	3380	3570	4240

The story of rice yields in Japan is similar to that of wheat yields in England, except that throughout the period the level for rice was higher in terms of actual weight. This is partly because rice grown in flooded fields usually has an assured water supply; and partly because rice fields have their own sources of soil fertility, in mud brought in by the irrigation water and in nitrogen-fixing micro-organisms. The early medieval rice yield in Japan was similar to that in India today.

As with wheat in England, the medieval rice yield in Japan was just about doubled by the second half of the nineteenth century, and this in turn has nearly been doubled again. The national average is now approaching 4300 lb., and as the results of recent research work are applied during the next few years this level will be passed. It would be reasonable to attribute at least half of the increase since 1880 to the use of chemical fertilizers and the balance to other factors.

A word should be said about the possibilities of further increases in Japan. The highest national rice yields in the world are obtained on limited areas of exceptionally fertile land in Australia and Spain. In these two countries average yields of over 5000 lb. of paddy rice per acre are regularly obtained. It might be doubted whether Japan, with its wide range of climates and soils—some being naturally of very low fertility—could reach this average. Yet there are many localities in Japan where whole villages harvest around 11,000 lb. of paddy to the acre. Such fields, known as "high yield paddy fields," are undergoing searching scientific investigation in the hope of finding out what they possess that other fields lack. If these studies are successful—and in the long run they are likely to be—the answer should provide a clue to raising yields to a far higher level than at present over most of Japan. It is not fantastic to expect that the Japanese may in time double their already high average. This will not be achieved by fertilizers alone, but fertilizers will continue to play a big part.

Rice in Taiwan

For comparison with the long history of agricultural improvement in England and Japan it is instructive to turn to Taiwan (Formosa), where agricultural improvement began within living memory: here we have almost under our eyes a picture of how a traditional type of Asian peasant agriculture can be developed and improved by modern methods. During the first half of this century, until 1945, the technical stimulus and training came from Japan; since then, agricultural research and development have been carried on by scientists from nationalist China, aided by American funds.

The result in terms of paddy rice production can be seen in Table III, the earlier figures being taken from Wickizer and Bennet [27]. The 1958 yield was 2700 lb., the slight fall in 1959 being due to a severe typhoon.

The rice yield in Taiwan early in the present century, with traditional farming methods that included local manures, was similar to that in Japan some 400 years ago, and through technical improvements, including fertilizer use, it was raised by about 40% in the years before the war. By the end of the war, as the result of an almost complete lack of fertilizers, the yield fell back

TABLE III

RICE YIELDS IN TAIWAN

Year ..	1910–11	1920–1	1934–8	1946	1950–1	1959
lb./acre ..	1555	1632	2195	1677	2168	2650

nearly to where it had started from—which shows how great a part fertilizers had played in securing the pre-war increase—and since then, with increased usage of chemical fertilizers and other improvements, the yield has been raised well above the pre-war levels. By 1959 the yield per acre was almost 75% greater than it was at the beginning of the century, and the extent of the wartime fall suggests that over half of this increase was directly due to fertilizers.

Bearing on this, a long-term field experiment in Taiwan gave average yields per acre over 24 years of 997 lb. without manure or fertilizer and 2303 lb. with complete NPK fertilizer [3]. Here the response to fertilizer was over 100%, but the yield on the unfertilized plot was below the pre-fertilizer average in Taiwan and that on the NPK plot was below the national average today, doubtless because the Taiwan farmers used local manures before chemical fertilizers were introduced.

Taking everything into consideration, the yield secured by traditional methods has apparently been increased by upwards of 50% by the use of fertilizers, though their effect cannot be isolated from that of the simultaneous introduction of new varieties of rice that were able to make use of heavy fertilizer applications.

The rice yield in Taiwan is still well below that in Japan, although fertilizer use is now quite intensive [20]. Field experiments show that still heavier applications could appreciably raise production, but a large gap, compared with Japan, would remain. Taiwan agricultural research workers feel that they are approaching an upper limit under existing conditions, and are undertaking special investigations to find out what factors are now limiting yields.

A considerable part of the answer probably lies in the fact that in this tropical and sub-tropical island two or even three rice crops are grown on the same land in the course of a year. Consequently, short-period varieties have to be used, and these do not have time to produce such massive crops as the slower-growing rice varieties of Japan. If the output of rice is taken per acre per year instead of per crop, Taiwan is already well ahead of Japan: where Taiwan land is double-cropped with paddy rice the average output per year is around 5300 lb. per acre.

DISCUSSION

Any broad conclusions drawn from the experimental results and national yield figures presented must be subject to individual variations related to the climates, the soils, the present stage of agriculture and other factors pertaining to each territory under review. Accepting this, it would appear from field experiment results that the direct response to fertilizers used at moderate rates in underdeveloped countries has varied around 50%, and that this figure should be doubled in order to take into account the effects of the other agricultural improvements which will inevitably be introduced along with fertilizers.

This conclusion has been confirmed by studying the changes in crop yields that have come about as countries beginning with primitive agricultural systems have improved them, firstly by using better farming systems and organic manures, and subsequently by introducing modern agricultural methods, including new crop varieties and chemical fertilizers (compare Figures 8 and 9). In such countries the primitive yields have been at least doubled by farming improvements of the traditional sort, and then doubled again by modern scientific methods, about half of the latter increase being due to the direct effect of fertilizers.

This prompts a further reflection on crop yields in agriculturally underdeveloped countries, where farming methods are of the most primitive kind and local organic manures are little used. In such countries the yields of cereals are so low that even if they are doubled by the use of fertilizers and other means the production of food per acre will still be small. This, however, will only be a beginning: the bigger crops will provide more residues for incorporation into organic manures; as agriculture improves, some form of mixed farming is likely to be introduced, bringing animals and their manure along with forage crops or grassland leys into the farming system; the fertility of the land will be built up until the improved yields of today become the basic yields of the future, so that still further improvements on these new basic yields become possible.

From the study of what has been achieved in western Europe and Japan in the way of raising crop yields above medieval levels, it would seem reasonable to suggest that, in the course of time, the very low yields secured in some of the underdeveloped countries can be doubled and then doubled again by using similar methods. A fourfold increase may seem too much to expect for a country like India that has such scanty and irregular rainfall in certain areas, yet a threefold increase in cereal yields could surely be attained in practice: in India this would result in average yields around 2000 lb. of wheat and 3400 lb. of paddy rice per acre, which are well below the rates obtained in more advanced lands.

Another pointer leading to the same general conclusion has been emphasized by Greene [6], who drew attention to the fact that the maximum yields in fertilizer experiments at research stations in underdeveloped countries are often many times as great as the average crop yields obtained by the farmers in the district round about. An example quoted by Greene was the production of from 1930 to 2246 lb. of seed cotton per acre at Samaru Research Station, Northern Nigeria, by the full application of modern agricultural techniques, including heavy manuring [8]. The farmers' yields of seed cotton in this area are only a few hundred pounds per acre. The writer himself saw the cotton crop growing in this Samaru experiment and can testify how completely it outclassed any of the cotton grown by the cultivators in the same district. Many similar examples could be given for food crops.

The speed with which food production can be expanded in the underdeveloped territories is very much a matter for the countries themselves: if their governments consider that the food problem is grave enough to justify sufficient expenditure of money and effort, both on experimental and development work and on advisory services, food production can be raised faster than any likely rate of population increase. The greatest need is for adequate advisory or extension services: with uneducated cultivators, relatively more trained supervisors are needed than in the more developed countries—and this means something better than one advisory officer in the field for every thousand farmers [24]. Large but not impossible amounts of fertilizer will be required, as Page has recently shown [14].

In this account nothing has been said about animal foods and all too little about irrigation. In the underdeveloped and overpopulated countries, cereals and other vegetable foods supply by far the greater part of the human calorie requirements, and this situation seems likely to continue. None the less, animals provide much-needed protein and accessory factors in human diet, so that the production of foods of animal origin must be increased. The possibilities of doing this, by manuring and in other ways, are great, as was shown by speakers at the British Association Symposium and in meetings of Section M (Agriculture): notably in the Presidential Address by Dr. William Davies. There is therefore no need to go into the possibilities here, beyond remarking that experience in countries like Australia and New Zealand has shown that the carrying capacity for livestock of natural grasslands can often be multiplied several times by using chemical fertilizers and improved herbage species. In most countries the productivity of the soil for human-food crops is also greatly increased by adopting rotations that include livestock and fodder crops or temporary leys. As the grassland management investigations of I.C.I. Ltd. in Britain have shown, profits as well as the production of milk and meat can be raised by the skilful fertilizing of grassland, combined with good management.

As for irrigation, there is no question that wherever the water can be found and applied in dry regions, irrigation alone will secure great increases in crop yields. But such increases tend to diminish as time goes on, and the soils will become exhausted by continuous cropping unless chemical fertilizers are also used. Where fertilizers are used, irrigation will greatly improve the responses, as has been exemplified in the wheat experiment in Mexico.

Even in the developed and industrialized countries considerably more food could be produced by the more intensive application of fertilizers along with other modern agricultural methods. In the U.S.A., for example, "100-bushel corn" (5600 lb. maize/acre) is widely regarded as a practicable target, whereas the present average is only 2900 lb. Individual examples of 200-bushel and 300-bushel yields have been reported [4]. Much of the technical knowledge is already available for use when it is needed, but at present it may not pay the farmers to produce such heavy crops, or the management effort involved may be more than many of them care to undertake. When the need for more domestic food production becomes acute in the highly developed countries it can be met.

As time goes on, however, the problem of raising crop yields will become progressively more complex and difficult in the developed countries. It is well known that the Law of Diminishing Returns operates when fertilizers are used; the curve for the effect on yield, or the response to extra fertilizer dressings, rises steeply at first but then flattens out at the higher rates of application. The underdeveloped countries are operating at the steep lower end of the response curve, and for them yield increases are easy to secure, but the countries having the most intensive systems of modern agriculture are already operating at the flat upper end.

Under all conditions the other factors limiting crop yields have a great influence on what fertilizers can do, yet these limitations operate most stringently at the upper end of the response curve. When the yield of a crop has been pushed so high that further increases in fertilizer use have little effect it becomes essential to give still more attention to the other factors limiting yields. If these limits can be removed, fertilizers will once more prove effective.

It is for this reason that better control of irrigation water forms a major theme in the research work now being done on paddy rice in Japan and Taiwan. When this and such other problems as the production of varieties still more resistant to disease and lodging have been solved, it will be possible to raise paddy yields even higher with the help of fertilizers. Again, dry-land crops, including grassland, in medium-rainfall areas are often restricted by lack of moisture from giving their maximum yields; water storage and a little irrigation at critical times, perhaps from sprinklers, can go far to overcome this and incidentally to help fertilizers to produce higher yields.

There is a great deal still to be found out by research at the top end of the yield curve; in intensively farmed countries the question "Why not top yields?" is no longer an academic one. In Japan, investigation into the special factors responsible for high-yield fields is already going on, and similar investigations might well be undertaken in many other countries. Examples of extremely high local yields in several countries have already been mentioned. We tend to take it for granted that individual fields may yield 8000 to 17,000 lb. of grain to the acre or more, although the national averages are only measured in hundreds or a few thousands of pounds. Much more investigation is needed into finding out exactly why some fields yield so highly when most of the land—even including well-fertilized plots on research stations—yields so much less. When practical answers to this problem are known, our earlier estimates of what scientific methods could do to increase crop yields will appear modest indeed.

REFERENCES

[1] ABRAHAM. T. P. (1959). *Fert. News* (India), **4** (12), 59–62, *Ind. Counc. Agric. Res., Res. Rep. Ser.* No. 1.

[2] BORLAUG, N. E. (1958). *Trans. N.Y. Acad. Sci.*, Ser. 2, **20**, 278–95.

[3] CHU, H. F. (1956). Fertilizer Use in Rice Production on Taiwan, TS, p. 1.

[4] DUNGAN, G. M., LANG, A. L. and PENDLETON, J. W. (1958), *Adv. Agron.*, **8**, 470.

[5] GAVIN, Sir W. (1951). *J. Min. Agric.*, **58**, 105–11.

[6] GREENE, H. (1960). Personal communication; circular letter to overseas correspondents (June).

[7] HALLIDAY, D. J. (1960). *Bull. Jealott's Hill Res. Sta.*, No. 10.

[8] KING, H. E. (1959–60). *Progr. Rep. Exp. Stas. Emp. Cott. Gr. Corp.*, N. Nigeria, 1959, p. 8; 1960, p. 6.

[9] LARA, G. A. F. DE (1957). *Agric. de las Americas*, **6** (3), 38 *et seq.*

[10] LARA, G. A. F. DE (1958). *Agric. de las Americas*, **7** (8), 34 *et seq.*

[11] MATSUO, T. (1959). *Rice Culture in Japan.* Min. Agric. Forestry, Tokyo. Pp. 1–5.

[12] NYE, P. H. (1951–4). *Emp. J. exp. Agric.*, **19**, 217, 275; **20**, 47; **21**, 176, 262; **22**, 42, 101.

[13] OBI, J. K. (1959). *The Standard DNPK Experiments.* Regional Res. Sta., Samaru, Zaria, Nigeria (not dated); p. 20 (stencilled).

[14] PAGE, H. J. (1959). *Outlook on Agriculture*, **2**, 203–12.

[15] RAMON, F. G. and LAIRD, R. J. (1959). *Agron. J.*, **51**, 33–6.

[16] RICHARDSON, H. L. (1946). *Emp. J. exp. Agric.*, **14**, No. 53–6.

[17] RICHARDSON, H. L. (1952*a*). *Trans. Int. Soc. Soil Sci., Comm. II and IV*, Dublin, **1**, 222–30.

[18] RICHARDSON, H. L. (1952*b*). *F.A.O. Int. Rice Comm.*, IRC/FP/52/18 (stencilled).

[19] RICHARDSON, H. L. (1956*a*). *Outlook on Agriculture*, **1**, 87–94.

[20] RICHARDSON, H. L. (1956*b*). *Proc. Fert. Soc.*, No. 41, pp. 22, 29, 30.

[21] RICHARDSON, H. L. (1960). Address to Brit. Assoc., Sect. M, Cardiff (*Adv. Sci.*, in the press).

[22] RUSSELL, Sir J. (1954). *World Population and World Food Supplies.* Allen and Unwin, London.

[23] RUSSELL, Sir J., and others (1960). *New Scientist*, **8**, 21st July and subsequent numbers.

[24] SLATER, Sir W. (1958). *Proc. Fert. Soc.*, No. 53 (Discussion), p. 17.

[25] STEPHENS, D. (1960). *Emp. J. exp. Agric.*, **28**, 1–15.

[26] TAMHANE, R. V. (1959). *Fert. News* (India), **4**, (12) 17–20.

[27] WICKIZER, V. D. and BENNETT, M. K. (1941). *The Rice Economy of Monsoon Asia*, Stanford Univ. Food Res. Inst., p. 318.

[28] YATES, F., FINNEY, D. J. and PANSE, V. G. (1953). *Ind. Counc. Agric. Res., Res. Ser.*, No. 1.

THE CONTRIBUTION OF CROP PROTECTION TO INCREASED WORLD FOOD SUPPLIES

E. Holmes

(*Plant Protection Limited, Fernhurst, near Haslemere, Surrey*)

In the course of the past two decades great advances have been made in the field of crop protection. Not only have efficient pesticides been developed and machines for their application, but various national and international bodies have been set up to provide technical and financial aid in the conduct of control operations, making it easier for peasant communities to take action in reducing crop losses and increasing food supplies.

It has been calculated in the United States of America that whereas in the mid-nineteenth century four farmers produced sufficient food for five persons, in 1940 one farmer produced sufficient for ten persons and, currently, one produces sufficient for twenty-four. Doubtless similar, if not quite such impressive, figures could be adduced for many other countries with a sophisticated pattern of agriculture.

In crop husbandry these advances have been produced by a wide variety of means, chief among which are:

1. Better methods of cultivation and usage of soils based on greater knowledge and better machines.
2. Better and greater usage of water based again on wider knowledge and the introduction of more intelligent irrigation.
3. The use of better planting material—seeds, cuttings, transplants, etc.—partly by direct selection and partly by the breeding of higher-yielding varieties.
4. The greater and more intelligent use of fertilizers, often on more responsive new varieties and, in some cases, the addition of minor elements to the soil.
5. Better means of crop protection, particularly in the last two decades.

To complete the picture mention must be made of the parallel developments of selection of farm animals, their feeding, and protection by veterinary products.

It is obvious that much of the benefit from the first four items will not be secured if the resulting crops are ravaged by insect and other pests or by fungous diseases, and if competition from weeds is allowed to any significant extent.

Numerous means of crop protection have been proposed, and many are now used. Cultural, mechanical and biological methods all have their place in world agriculture, but, despite many emotional and ill-informed statements to the contrary, all sober agriculturists and research workers agree that chemical means are and will for a long time remain the largest single factor in keeping crops healthy and free from weeds. This paper deals essentially with chemical means.

CONSUMPTION OF CROP PROTECTION CHEMICALS

Official and semi-official reports covering this subject fail to give any accurate idea of the rate of growth in consumption of crop protection chemicals on a world basis because the statistics are quite inadequate to reveal such information. We know, of course, that usage of chemicals has increased greatly everywhere during the post-war years, but except in certain countries (e.g. U.S.A.) and for well-known materials, such as DDT, BHC and 2,4-D, it is impossible to determine the magnitude of this increase in comparable terms. Production figures are not a sound basis for determining usage, because they take no account of exports. The most complete statistics—those published annually by the F.A.O.—are not comparative, because the concentration of active ingredient is variously stated, some countries expressing usage in terms of 100% a.i., others as dilute products, and others again giving no specification.

The picture is complicated by the replacement of one type of product by another, as new and better materials become available. In the U.S.A., for example, the consumption of DDT reached a peak in 1951–2 of 32,378 tons but dropped to 24,248 tons by 1954–5. During this period such new materials as toxaphene, dieldrin, parathion and methoxychlor were increasing in favour, sometimes because pests resistant to DDT had made their appearance, sometimes because the new products were found to have specific attributes which favoured them for particular outlets. In other countries, however, DDT usage may still be expanding or even only just beginning. The same confused and incomplete picture is obtained from an examination of data on herbicides and fungicides.

It may be concluded that neither production nor consumption figures in the present imperfect state of our records can teach us more than we know from general observations, i.e. that crop protection methods are being increasingly used throughout the world and that the volume of use is usually in proportion to the degree of sophistication of the country's agriculture. The acreage sprayed annually against pests, diseases and weeds expressed as a proportion of the total acreage would give us a far better idea of the spread of crop protection techniques, but statistics of this kind are nowhere available. The world sales value of pesticides is probably in the region of £200 million a year, but the value of the crops saved is very much greater than that.

FACTORS INFLUENCING SPREAD OF CROP PROTECTION

The tremendous growth in the use of means of crop protection, both during and since the last war, has been due to a variety of factors, chief among which are: improvements in chemicals and the development of machinery and techniques for their application; the provision of government and international aid; the development of co-operative movements, and education. Each of these items will be the subject of a separate section of this paper.

One general point, however, may be made regarding the acceptance of crop protection products, particularly in undereducated, underdeveloped territories. It is normally far easier to persuade a grower to use a product to control a particular pest if that product can be applied with successful results after the appearance of the pest; chemicals that have to be applied days, weeks or even months before the pest or its effects are obvious are much less popular. The exception to this generalization occurs with the fungicidal seed dressings, for here the demonstrable benefit is usually so large in relation to the tiny outlay, even though that outlay occurs six or more months before harvest, that growers are prepared to accept the expenditure as an insurance premium.

Improvements in Chemicals

Significant use of a crop protection chemical really began with the use of Bordeaux Mixture on grape vines to control downy mildew in France fairly late in the nineteenth century. With few exceptions development was slow until the thirties of this century, being dependent upon the availability of such natural plant derivatives as rotenone from derris, nicotine and pyrethrum; by-products such as cresylic acid and naphthalene from coal tar; the petroleum oils and their emulsions; and the readily procurable chemicals such as the arsenates, silicofluorides, copper compounds, sulphur and simple sulphur compounds, borates and chlorates. The exceptions include the organo-mercury compounds, first used in Germany in seed dressings to control seed-borne fungous diseases of cereals; the nitrocresols, first used in France both as insecticides and as weedkillers; and the early beginnings of the use of organic chemicals such as salicylanilide and the organo-sulphur compounds in Britain, Germany and the U.S.

The real beginning of the new era came with the Swiss discovery of the insecticidal value of DDT, announced in 1939. This was followed closely by the British discoveries of gamma-BHC, MCPA, 2,4-D and IPC in the early forties, the German discoveries of the first range of organo-phosphorus insecticides about the same time; and the subsequent development of a very wide range of new organic insecticides, fungicides and weedkillers in the U.S.A. and a number of countries in Europe.

These discoveries have had revolutionary effects:

1. They make it possible to control a much wider range of pests of all kinds.
2. Because of the greater specificity of some of the insecticides and weedkillers, better direct jobs could be done with fewer undesirable side effects, such as killing desirable insects or doing undue damage to crops.
3. Because of the extreme activity of many of these chemicals the small amounts needed per acre made it economically possible to control pests previously not considered practicable. As a corollary to this there has been a great upsurge of usage on extensive farm and plantation crops as distinct from intensive market garden, glasshouse and orchard crops.
4. New systems of crop rotation were made possible, e.g. by using selective weedkillers the root break for control of weeds could be eliminated.

Some of these products, however, have certain disadvantages and a few examples may be given to show how these are being overcome.

When DDT was first introduced it was found to give excellent control of codling moth. But if used on the second brood in England, for example, it killed off parasites and predators of the red spider, leading to an upsurge of this latter pest. It is now possible to use, say, an organic phosphate derivative that is not only excellent against codling but gives a good measure of control of red spider while being less toxic to the desirable insects.

Similarly, the organo-sulphur fungicides, such as zineb, while being less intrinsically fungicidal against potato blight than copper fungicides, are often better in practice because the direct phytotoxic effect on the potato foliage is much less.

In the case of the hormone-type weedkillers MCPA did, and does, an excellent job in controlling many deleterious weeds in cereals. If, however, the cereal is undersown with clovers these may be seriously damaged. The development of MCPB or mixtures of MCPB and MCPA has gone a considerable way to correcting this trouble.

Developments in Machinery

While it is important to discover new chemicals for controlling plant pests and diseases, it is every bit as important to provide suitable means for their application under widely different conditions of farming. These may vary from a loosely woven cotton bag through which a dust may be shaken or a primitive syringe made from a length of bamboo for the application of a liquid, at one extreme, to the most elaborate tractor-mounted or tractor-drawn multi-nozzle, air-blast spraying machine or the aeroplane duster or sprayer, at the other. Devices other than machines are employed on occasion, for example, smoke-producing compositions based on pyrotechnic mixtures containing insecticidal or fungicidal active ingredients.

Very great advances have been made in the last fifteen years, the more significant being:

1. The development of low-volume machines and techniques, and of formulations of active crop protection products to match.
2. The production of small motorized knapsack dusters and sprayers, as a result of the availability of reliable two-stroke petrol engines.
3. The development of new aeroplane dusters and sprayers and the technique of using the basic machines not only for the protection of diverse crops in various countries, but for entirely different purposes such as surveying and map-making, in order to keep the aeroplanes in the air a sufficient number of hours per year to make them really economic.

Low-volume spraying machines were known in the thirties, but at that time they were mostly based on the paint-gun principle in which small volumes of high-pressure air were used to provide a very fine spray with little carry or penetration. This defect was largely overcome by using simpler

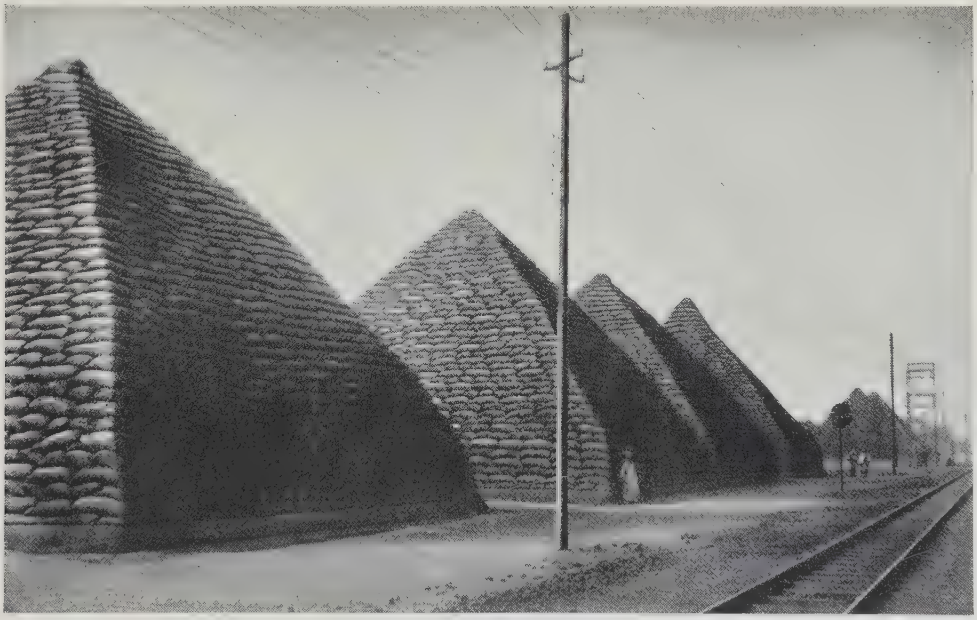

FIG. 1. Groundnut storage in Northern Nigeria. Each pyramid is composed of 9000 bags and weighs 750 tons. (Photograph by courtesy of The United Africa Co. Ltd.)

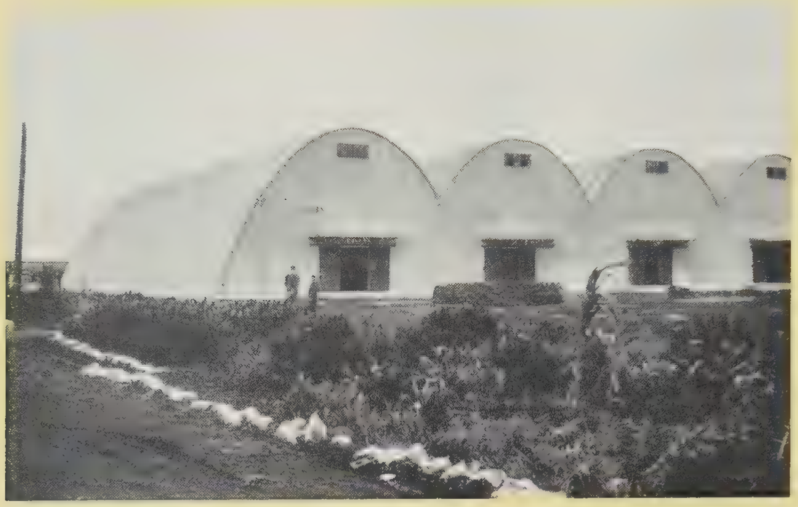

Fig. 2. Modern Ctesiphon grain stores used by the Maize Control Department, Kenya.

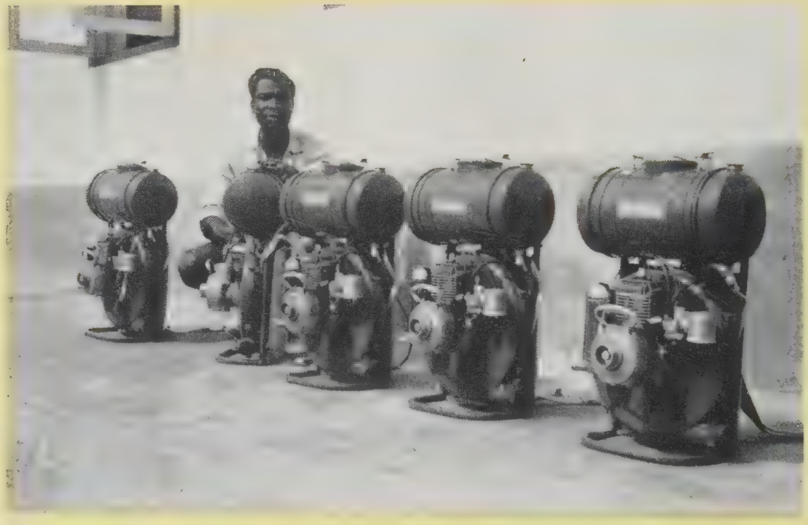

Fig. 3. The type of motorized knapsack sprayer now widely owned and used by cocoa farmers in West Africa.

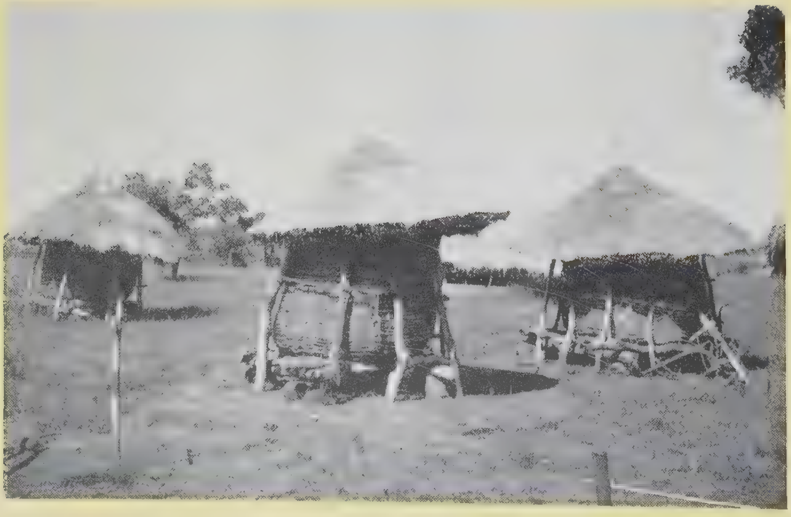

Fig. 4. Native grain stores in Kenya.

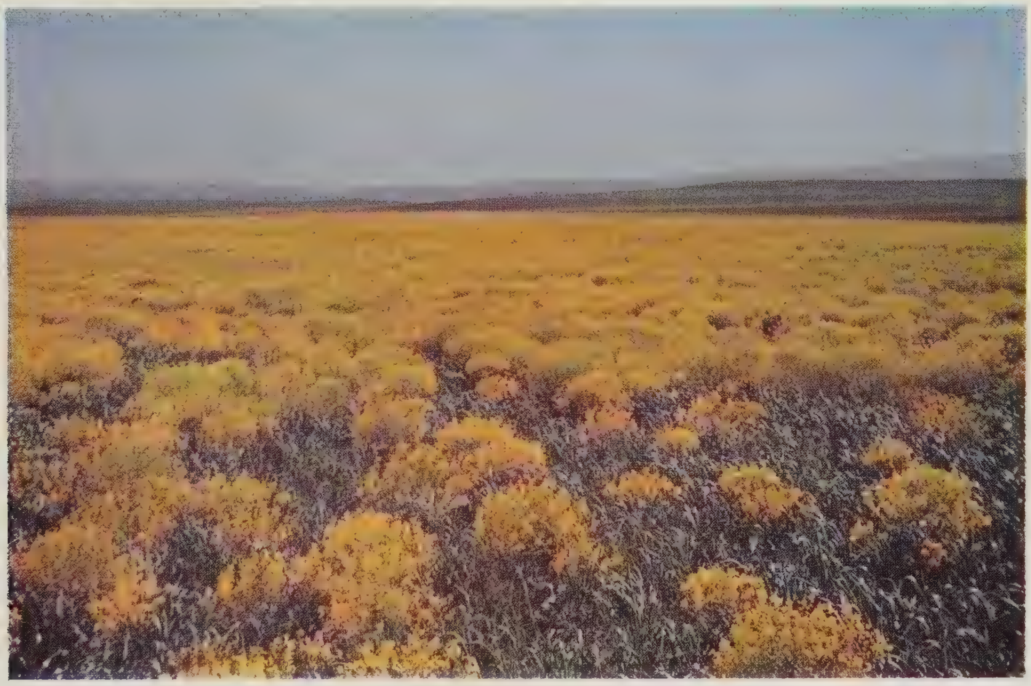

FIG. 5. A serious infestation of wheat in Turkey by a cruciferous weed, *Boreava orientalis*, now controlled by aerial spraying with MCPA or 2,4-D.

nozzles and large volumes of relatively low-pressure air to break up the spray and to carry the droplets, but the machines were expensive and somewhat cumbersome. Refinements of them are widely used for medium-volume application to tree crops grown in plantations, where weight is relatively unimportant and the cost bearable.

The really big advance in application to ground crops came with the development in the late forties, first in America and later in Britain and the rest of the world, of the simple hydraulic low-volume sprayer, exemplified by the weed sprayer used by the tens of thousands in Britain. Provided the product to be sprayed is a clear liquid, or the machine has a really adequate filtration system, such machines can spray efficiently as little as four or five gallons per acre, though for biological reasons rather more is usually preferred. These machines are really efficient for such purposes as spraying hormone-type weedkillers on cereals or grassland, insecticidal solutions to kill flea beetle on brassicas, or fixed copper fungicides to control potato blight. Moreover, a tractor-drawn model can be bought for as little as £50.

For many countries, particularly those supporting a peasant community, the physical difficulties as well as the cost of applying crop protection chemicals have been a severe handicap to efforts in introducing control measures on a general scale. Simple machines may not be good enough to achieve the biological results desired; and new techniques, such as concentrate or low-volume spraying may call for apparatus that is too expensive or too elaborate for the average peasant farmer.

In a later section of this paper a description will be given of the control of capsid bug of cacao in West Africa. The tremendous extension of this work, with great benefit to the economy of the countries concerned, has largely been made possible by the provision—particularly by continental manufacturers—of small petrol-driven, knapsack sprayers (Figure 3) that can readily be transported by local farmers through their jungle-like holdings, often quite unsuited to the type of power sprayer normally used for orchard work in Europe and America. But native cultivators are not experienced in using such devices and are apt to be a little unsympathetic to delicate mechanisms, so that a prerequisite for success is the provision of really adequate, widespread mechanical servicing stations.

In 1955 the Ministry of Agriculture in Ghana imported some 25 portable mistblowers for development and training purposes. Their large-scale spraying operations in the next year called for 500 machines and during the subsequent three or four years farmers were enabled by subsidy to purchase their own sprayers. Today (1960) nearly 50,000 shoulder-mounted mistblowers of various kinds are owned and used by the peasant farmers of Ghana. At the present rate of subsidy these machines cost the farmer £14—less than one-third of the actual cost of the majority of the makes in use.

Another example of modern application methods concerns the use of aircraft—fixed-wing or helicopters. Ordinary fixed-wing aircraft were used in the twenties and thirties; these were usually relatively cheap adaptations of second-hand units originally designed for other purposes, and they could be made to pay even when flown for only short periods during the year. Such machines are still used, particularly in the U.S.A.; but with the desirability of having special machines designed for the specific use, which inevitably means much higher costs, the real development has come in the technique of switching them to a variety of tasks. For example, a machine used for applying weedkiller or potato sprays in Britain can, at other periods of the year, be switched to spraying insecticides on cotton in the Sudan, or copper fungicides on bananas in Central America. By such means the annual depreciation on the machine and the expenses of pilots and attendant ground crew can be spread over a great many more acres sprayed.

Development of Techniques

Quite apart from devising new machines for the application of chemicals, much thought and effort has been expended over the years in developing techniques of using chemicals for general purposes in crop protection.

A classical instance is seed dressing. Ever since Provost in 1807 discovered that bunt of wheat was carried over from season to season as spores on the seed grain, this and similar diseases of cereals and other crops have been efficiently and cheaply controlled by chemical seed dressing. The practice rapidly expanded with the discovery in 1912 of the organic mercurials, and today a very large proportion of all seed grain is so treated in countries with advanced methods of agriculture.

But the tables have been turned in the case of paddy "blast" disease (*Piricularia oryzae*) which affects more than two million acres of rice in Japan or about a quarter of the crop. Control is effected by means of organo-mercurial products, originally devised for seed treatment but now used as dusts and sprays for which satisfactory application techniques were worked out several years ago. In 1953 some 7000 tons of diluted organo-mercury compounds were used, but as a result of widespread education, demonstration and propaganda the quantity now applied annually is in excess of 50,000 tons. Rice production has been increased through treatment by 10% or more and quality has been improved [5].

Until the late forties the only means of reducing the damage caused by such soil-inhabiting pests as wireworms were by cultivation, by growing resistant species or varieties of crop plants, or by direct soil treatment with chemicals. This last method, for purely mechanical reasons, is extremely difficult and, consequently, is expensive. A change of technique very largely solved the problem. It was found in Britain that the incorporation of a small amount, say 20%, of a suitable insecticide such as gamma-BHC in the conventional mercurial seed dressings for cereals gave a very high degree of protection from wireworm damage. Because a very active insecticide is introduced into the soil alongside the seed grain, i.e. where it will do most good, the method proved practical and is now widely used.

Yet another new method of crop protection is due to the development, largely in the last fifteen years, of systemic insecticides such as some of the organo-phosphorus products. When sprayed on plants, sometimes when applied to the soil in which they are growing, these chemicals enter the sap stream and move about freely in the tissues, thus making the plant toxic to attacking pests. The more persistent chemicals even move into the new growth so that, to use an Irishism, they kill insects on parts of the plant which were not present at the time of spraying.

To the above may be added techniques of forecasting outbreaks of pests and diseases, as a result of which it is possible to make more effective use of crop protection products, in some cases at lower costs. For example, observations by Dr. W. D. Mills of Cornell University have shown that apple scab infection is related to temperature and to the length of time the leaves remain wet, and from records of these two factors a forecast can be made as to when infection has taken place, curative mercury sprays must then be applied within five days of its onset. The system gives improved control because the fungicide can be applied at the optimum concentration when the disease is present on the tree; it also reduces the number of spray rounds required each season. It can of course only be used on varieties that tolerate mercury sprays. Similar work has been done in forecasting outbreaks of potato blight, and in this connection readers will be aware of the Beaumont Scale.

Again the control of blister blight of tea in Ceylon by means of copper fungicides, using 20–26 spraying rounds per annum, costs estates about 3% of their expenditure on production—making a total for Ceylon of about £750,000 yearly. Attempts are being made to reduce this cost by a forecasting system based on sunshine records, so that spraying need only be carried out when the period of sunshine during the four preceding days falls below twenty hours [32].

Government and International Aid

Pests and diseases often reach epidemic proportions of such importance that government or international action is necessary to prevent the damage from causing widespread ruin. Countries dependent on one or only a few major crops for their economic survival are forced to provide assistance in one form or another. Many intergovernmental bodies have also been set up to promote collaboration since the first of these—the Phylloxera Convention—was established in 1881. This required preventive action by means of quarantine measures. In the years which followed, quarantine regulations in the different countries became so diverse that some degree of standardization on an international basis became urgently necessary. This need was met by the International Plant Protection Convention which came into force in 1952.

Within the framework of this Convention, the forty or more contracting governments agree to set up national services as well as to take part in regional control campaigns organized to meet emergency outbreaks. They co-operate also, through the World Reporting Service, in the compilation and dissemination of information on pest and disease outbreaks. Regional agreements, often in association with the International Convention, have also been formulated in recent years, notably: European and Mediterranean Plant Protection Organization (1951); Organismo Internacional Regional de Sanidad Agropecuaria (1955), covering Central America and Mexico; Plant Protection Agreement for S.E. Asia and Pacific (1955); and Phyto-sanitary Convention for Africa South of the Sahara (1956).

The establishment of these and many other inter-regional and regional bodies would have been difficult if not impossible without the central, co-ordinating and advisory functions of the Food and Agricultural Organisation (F.A.O.). From its inception in 1945 the F.A.O. has encouraged member governments to co-operate and, by providing technical and financial aid, has contributed directly to the setting up of campaigns to prevent crop losses.

No other pest or disease can match the locust in its capacity for widespread crop destruction, and it is in locust control that international campaigns have attained their most comprehensive degree of organization. Much still remains to be done but the post-war years have seen tremendous strides in the realms of joint action and responsibility. Money has been found through the F.A.O. and other agencies to study the life-cycles of locusts, survey outbreaks, supervise outbreak areas and finance the chemical control campaigns. Efforts can now be directed not only to killing the locust swarms but to preventing outbreaks occurring at all.

The picture is always changing; new epidemics occur and countries must be ready to tackle them quickly. Recent years have witnessed the spectacular spread of maize rust from Sierra Leone through Central Africa to Kenya and the islands of the Indian Ocean; *Tristeza*, a virus disease of citrus, wiped out large areas of commercial citrus plantings in Argentina and Brazil; the tea industry of S.E. Asia was seriously threatened by blister-blight; fruit crops in Central Europe suffer heavily from the fall webworm, and in Central America from the Mediterranean fruit fly. Many more examples could be quoted.

It is not only governments that need to take preventive or curative action against these menaces. The farmer himself must constantly watch for and try to control pests and diseases that reduce his yields or affect the quality of his crops, even though these are not actual or potential threats to national economy. In the underdeveloped countries especially, where the low level of husbandry or adverse climatic conditions leave insufficient profit margin to the farmer to practice crop protection methods, the cultivator needs state assistance if he is to progress beyond subsistence level agriculture. Many instances could be cited of State assistance in the form of subsidies to buy chemicals or machines, and in providing plant protection services, central seed dressing establishments, encouragement and help to farmers' co-operative organizations and so on. In some cases the scale on which assistance is necessary is too great for the government and foreign aid in one form or another has to be sought.

The U.S. International Co-operative Administration (I.C.A.), including within its scope the activities of the "Point Four" programme of technical assistance to underdeveloped countries, continues to help many countries to improve their agricultural methods. In Pakistan, for instance, I.C.A. is the main contributor of foreign exchange in a programme for local formulation of pesticides, now all imported. In 1960 I.C.A. is expected to contribute about £700,000 to the purchase of chemicals and machines; in 1961 at least £1·25 million of foreign currency will be required to purchase formulation machinery, and expenditure at this level is likely to continue throughout the second Five Year Plan period.

Mention must also be made of the Expanded Technical Assistance Programme of the F.A.O. and the Colombo Plan—both extra-State organizations which are helping, by the provision of technical experts or financially, to solve pest and disease problems in countries not yet equipped to tackle them on their own. Their contribution towards increasing world food production, directed as it is to those countries where shortages are chiefly felt, cannot properly be measured because in the last resort the result of their efforts depends on the response of individual farmers.

Co-operative Movements

In a large agricultural community made up of small peasant farmers, the problem of introducing crop protection practices is partly educational, partly financial. Many countries today, principally in tropical areas, are unable to make progress in controlling pests and diseases because there is neither sufficient money to buy the materials necessary nor adequate distribution channels through which such materials can be sold and bought. Some of these countries are profiting from the financial and technical aid of international organizations, and some are also helping themselves through co-operative movements. An excellent example of this may be seen in Nigeria.

In Western Nigeria alone there were in 1954 371 Co-operative Produce Marketing Societies with a registered membership of 24,000; some 14,000 other farmers belonged to other co-operative societies, giving a total membership of 38,000 —almost one quarter of all cocoa farmers in the region [3]. Cocoa in Western Nigeria suffers severely from the disease "black pod" (*Phytophthora palmivora*) and the Department of Agriculture had demonstrated how this could be kept in check by a simple technique of spraying with a cuprous oxide fungicide. How was this large number of small farmers to get sprayers and chemicals and learn how to use them?

The Co-operative Supply Association undertook to import equipment and chemicals and to sell them on their customary credit terms through the Societies to their members. The Department of Agriculture were responsible for training farmers in the spraying technique, and the C.S.A. agreed to sell only to members holding the recognized training certificate. By this co-operative exercise two important objectives were achieved: the farmer was able to obtain credit for purchasing his requirements; the particular crop protection technique was properly applied by trained farmers.

The activities of co-operative societies are generally controlled by a government department and they vary widely in their purpose and function. By no means all tropical countries are so advanced in their co-operative organization as Western Nigeria, but with increasing education it is to be hoped that this situation will steadily improve and lead to greater use of crop protection chemicals. However, before co-operatives are allowed to enter this field it is of the greatest importance that the particular technique it is proposed to use should have been properly evaluated, especially as regards its technical and economic value to the farmer.

Education in Crop Protection

The practical control of pests, diseases and weeds is nowadays an essential feature of the curricula of agricultural colleges. Such studies deal with the technology of the subject—the "why, where, when and how" to apply chemicals to crops for dealing with specific troubles. Farmers and agriculturists alike need this knowledge just as much as they need to know how to prepare a seedbed, to prune a fruit tree, or to take any other step to good hsubandry.

There are, however, large areas of the world where farmers still follow the methods of their forefathers and where prejudice and superstition present formidable barriers to agricultural education. In such territories general improvement in husbandry must precede the introduction of the more erudite techniques such as crop protection. The reason for this can be purely one of economics: yields may be so low under the existing system of culture that the benefit from protecting crops against pests and diseases is too small to pay for the cost of doing it. The effort in these countries must be towards raising the general standard of education and by this means making the farmer better aware of what he stands to gain by improving his standard of farming.

Apart from the colleges and farm institutes that teach crop protection, it must not be overlooked that the chemical companies selling crop protection products contribute in no small measure to the dissemination of knowledge on this subject. The larger companies have their own research stations devoted to experiments in pest, disease and weed control and to these come visitors from all parts of the world. Some conduct courses, organize conferences, employ education officers—not solely to educate their own staffs but students and the agricultural officers of government departments. The scope of their work extends well beyond indoctrination in the use of proprietary products and much of the world's research and field experimentation in crop protection can be said to owe its inspiration and financial support to the sponsorship of chemical manufacturers.

On the more academic side, crop protection is a composite subject derived from entomology, botany, mycology, chemistry, physics and engineering and the more specialized aspects of those sciences. Sir Frank Engledow [16] has expressed this in the following words: "A body of practical factual knowledge, even if much greater than that now available, would be no foundation for an advanced university course. For deeper scientific understanding of control, more knowledge of insect physiology and its chemical responses, of insect reproduction, and of population phenomena, of insect-host relationship, is indispensable, with an analagous requirement for plant diseases. There is not likely to be, for a long time, enough primary knowledge and basic principle in these fields to constitute a subject of advanced teaching."

In a subject like this, where practice is all the time advancing more quickly than the sciences that support it, we must make doubly sure that our teaching is based on empirical knowledge derived from sound field experimentation.

BENEFITS FROM CROP PROTECTION

Although the title of this paper refers specifically to increased world food supplies and therefore implies the use of crop protection products on food crops only, protection is just as important on industrial or cash crops such as cotton and rubber. The grower who obtains benefits from these crops has more money to spend on the improvement of those grown as food for his family and on raising the economic status of his farm.

It would be possible to give data of dubious accuracy on returns obtained from the successful control of pests and diseases on numerous crops in all parts of the world, but it has been felt better to choose only four specific instances, where the information is perfectly clear and the figures unassailable, to illustrate the advantages that can be secured in each field of plant protection by applying the right methods on a large scale.

Cocoa Capsid in Ghana

The total cocoa production of Ghana—far and away the largest producer in the world—fell from 300,000 tons per annum to 225,000 between 1935 and 1951 owing very largely to the depredations of the capsid bugs *Sahlbergella singularis* (Hagl) and *Distantiella theobroma* (Dist) and to damage caused by swollen shoot disease and blackpod disease.

An estimate quoted by Hale [19] puts the annual losses due to the capsids at 60,000–80,000 tons, swollen shoot at 50,000 tons and blackpod at 25,000–40,000 tons at a time when the cocoa production was 215,000 tons. The maximum crop then envisaged, assuming these losses to be additive, was therefore of the order of 365,000 tons. This maximum, using the existing varieties, becomes most interesting when compared with the possible yields that can now be expected following full-scale capsid control programmes.

The average production in Ghana with its 3 million acres of cocoa in bearing is now 180–220 lb. per acre, and because more than 30% of the country's plantings are over 30 years of age yields are declining rapidly. Indeed, the survey of World Cocoa Production by the F.A.O. in 1955 led the authors [2] to make this comment on the age of Ghana cocoa: "A vast increase in plantings will be necessary if the Gold Coast is to attain some expansion of—or perhaps even to maintain—its current production (220,000 tons) after 1960, not to speak of regaining its pre-war production record. During the next 5 years only a great reduction in losses through diseases and pests can prevent a further decline. In the meantime 7–10 million trees will be lost annually to swollen shoot alone!"

The average yield per acre in Ghana was used as a guide when selecting the greater part of the very large number of experimental plots treated and observed over the past few years by the joint staffs of the Ghana Department of Agriculture, the West African Cacao Research Institute at Tafo, and Plant Protection Ltd. In 1957 Hammond [21] reported that on such typical cocoa, standard capsid control measures were followed by astonishing yield increases. Taking main crops only, yields were increased by 623% in the 3rd year of treatment on units producing under 100 lb./acre in the 1st year. Where the initial yield had been 100–200 lb./acre the increase was 244%, and the increase obtained on the better units declined to 43% where units yielded over 600 lb./acre at the start.

The capsid control measures used in the above experiments consisted in mistblowing 1 pint Gammalin 20 (i.e. 4 oz. gamma-BHC toxicant) in 5 gallons of spray per acre, repeating the application 4 weeks later. Localized areas were retreated as new damage was observed.

In the years following, similar treatments on a wide scale in the Eastern Region and Ashanti again gave spectacular results: by the 3rd year of treatment yields of cocoa per acre had risen from 160 to 591 lb. in the Eastern Region, and from 333 to 825 lb. in Ashanti [38].

These remarkable responses to spraying with gamma-BHC under extensive experimental conditions were the basis of a very large spraying campaign organized by the Ghana Government. The 1957–8 season saw the first substantial activity and in the current 1960–1 season it is expected that well over 2 million acres will be sprayed.

It is interesting to speculate on what effect capsid control on such a large scale will have on the production of cocoa in Ghana. Replanting which followed cutting out, starting in 1946, made little progress and by December 1956 only 15,226 acres [4] had been re-established, representing 13% of the area cut out. This of course was slow to affect yields, for replants do not give an economic crop for some years. Moreover, during this ten-year period about 63 million trees were removed, reducing the production by a total of 12,000 tons of cocoa [2]. There was, however, a net gain, production rising from 230,000 tons in 1952–3 to 245,000 in 1955–8. Swollen shoot replanting, therefore, is of relatively little significance in the very marked upsurge of yield since 1954–5.

Replanting as part of the rejuvenation programme is much more significant. New plantings total 100–150 million trees, but according to a 1955 report [2]: "Even if all these became established they will not counterbalance, during the next five to seven years, the decline in yield of the 250 million trees which are now over 30 years of age. The total production that can be expected from the post-war trees is only 35–50,000 tons."

There are two remaining major factors, the weather and the Capsid Control Scheme. The effect of the weather and undisclosed production (illegal export) will perhaps be the cause of annual variations of up to 25,000 tons; but if the results of the capsid control experiments quoted above can be applied on a country-wide scale, the very substantial rise in production in the last two years can be accounted for. The average rise in yield after a year's spray programme is about 110% at the country average yield level of 200–220 lb./acre, and in the second year of treatment a further increase around 50% is obtained.

In 1957–8 spraying was expanded to field scale and some 450,000 acres were treated, giving about 45,000 extra tons of cocoa. In 1958–9 500,000 acres were initially sprayed and 450,000 acres given retreatment; this would by calculation give an extra production of 70,000 tons. In 1959–60 it was estimated that 2,000,000 acres were sprayed, half for the first time and half given retreatment; this would theoretically give an added 150,000 tons of cocoa and raise production from the present record of 315,000 tons to 450,000 tons—a level never before contemplated. It remains to be seen whether the full potential advantages of the spraying scheme will be realized.

Conservation of Stored Food

The attention given to the conservation of food once the harvest has been won has been, and still is, all too small. The reason for this may be that a farmer watches his crop daily and quickly notices anything going wrong, but once the harvested crop is put into store it is out of sight and frequently out of mind. In granaries and warehouses too, the control of insect pests does not receive the attention it merits.

The amount spent on food conservation has never been on the same scale as that for crop protection. Parkin [34] compared losses from insect pests in the U.S.A. in 1937 and 1939 in the field and in store with the amount spent on control measures. For stored products the cost of control was only 2% of the value of the produce destroyed, compared with 12·3% for crops and farm animals and 15·4% for forests. This relationship can well apply today, although the proportion spent on control measures has increased.

Estimates of losses due to insect attack in stores have mostly been of a very general nature. The F.A.O. [1] have published an estimate of 5% loss annually through insect infestation of all harvested cereals, peas, beans and oil seeds, representing half the quantity of these products entering into world trade. This was considered to be a conservative figure, since most of the damage occurred in tropical and sub-tropical countries, especially in underdeveloped areas where information on losses is largely lacking. Bishopp [9] estimated the annual loss in 1951 caused by insects to foodstuffs in the U.S.A. at $4000 million, of which insect damage to stored cereals accounted for $600 million. Eden [15] records that as much as 50% of the maize stored through the summer on Alabama farms was destroyed by stored grain insects and that the annual loss during 1948–52 in Alabama was 25%, or 11,000,000 bushels.

A great improvement has taken place since DDT, BHC, methyl bromide and other synthetic pesticides came into widespread use. Infestations are no longer transported about the world in a manner such as that quoted by Cotton and Gray [13] in 1948, when 1¾ tons of weevils were sieved from 145 tons of maize; grain transported in bulk today is relatively clean. Nevertheless heavy infestations are still too common in tropical countries where peasant farmers store their grain throughout the year in their own homes or in small stores nearby (Figure 4). Modern stores, used for maize in Kenya, are shown in Figure 2.

Precise observations on the extent of losses in store due to insects are rare. Hall [20] has recorded that maize stored for twelve months in a British tropical country without control measures showed an apparent loss in weight of 3–4%, but after allowance was made for insects and their frass in the samples the true loss was nearer 14%. Similar information is available for sorghum in the Belgian Congo [30], and in a bazaar in Tanganyika insect damage was found [22] to cause losses in weight of rather over 40% in sorghum and cowpea, and lesser damage to several other native crops. Observations on damage have been recorded for rice in the U.S.A. [8] and in West Africa [20]; and for stored peas and beans in the Belgian Congo [29] and in Rhodesia [12].

Howe [24] reported an average net loss of 4–5% in groundnuts stored for twelve months in Nigeria. He pointed out that in normal practice most of this loss would have been undetected, because the insects' bodies and excrement remained and because of a gain in moisture content of the nuts during transit to the port for shipment. Losses with groundnuts are not confined to weight: insect infestation of broken nuts can increase the free fatty acid of the oil from 3·1% to 13·4% during twelve months' storage, and the loss of edible oil is about double the acid value. Further, the cost of refining this oil increases with rises in the free fatty acid content.

Before the last war there were no efficient products which could be used for control. Today, with our wide range of efficient synthetic insecticides, the occurrence of losses can only be attributed to ignorance or to the inability to apply the right product, usually because of failure to persuade farmers and marketing organizations that control is an economic advantage and, especially in underdeveloped countries, failure to set up organizations to distribute insecticides and to give instruction in their correct use.

Prior to 1940 insect pests of stored products were commonly controlled with fumigants, and all of these had serious limitations. Hydrogen cyanide was not only extremely poisonous but was readily sorbed on foodstuffs and would not therefore penetrate bulked or stacked grain; it could only be used for fumigating empty buildings or ships. Ethylene dichloride, ethylene oxide and carbon bisulphide could treat bulks or stacks, but all were inflammable and had to be mixed with non-inflammable materials to reduce explosion risks, hence large volumes were required for small quantities of grain. Calcium cyanide had to be mixed with the grain and there were residue problems if the grain had too little moisture in it to liberate all the hydrogen cyanide. The only other insecticides available were derris, which was not toxic enough to grain insects to be of any use, and pyrethrum, which was looked upon merely as a spray giving a deposit of short insecticidal duration. Nothing was therefore available to protect grain against reinfestation after it had been fumigated.

Fumigation practice was greatly extended during the war by employing the non-inflammable and highly insecticidal properties of methyl bromide. The gas was absorbed very little by foodstuffs and hence penetrated well into bulks and stacks, yet left the commodity very readily during the subsequent airing period. Further, it was highly toxic to the insects and only small quantities were required. Methyl bromide was developed primarily for use in grain silos in which special trunking was installed to circulate the gas through full bins and ensure good distribution; later it was used with stacks covered with gas-proof tarpaulins.

Similarly DDT and BHC revolutionized the insecticidal treatment of grain, since they were highly toxic to most stored grain pests and one application remained active for months. Thus, after fumigation, warehouse walls and stacks could be protected against reinfestation for long periods. These surface treatments were later supplemented by direct admixture of insecticides with grain, as a substitute for fumigation or as a prophylactic measure for clean grain. This work was pioneered by Le Pelley and Kockum [31] in East Africa. They showed that 1 p.p.m. of gamma-BHC (lindane) or 25 p.p.m. pyrethrins could protect clean shelled maize against insect attack in a very heavily infested store for 15–16 and 9–12 months respectively. At the end of this time only 6·0% of the grain was damaged in the BHC-treated bags, as against 66·0% in the untreated. Kockum [26] obtained successful results with cob maize: he found that 22·7% less weight of maize was shelled out of untreated cobs stored in cribs for six months compared with lindane-treated cobs. This work led to the widespread adoption of lindane treatments of grain in Kenya, Tanganyika and Ghana.

The spectacular savings demonstrated by Kockum in 1953 have not been possible in countries where the admixture of insecticides such as DDT and lindane with grain is prohibited on toxicological grounds, and where pyrethrins are too expensive. Nevertheless treatment of the surface only of bags can account for substantial saving: Hall [20] reports that close stacking of maize bags and lindane dusting of their surfaces can cut losses by half.

In the course of work with the newer insecticides it became obvious that some insects were not being controlled with complete success. Examples were the Khapra beetle (*Trogoderma granarium*) which recently caused considerable alarm in the U.S.A. when it was first reported there, the sawtoothed grain beetle (*Oryzaephilus surinamensis*) which has recently become the most important pest of farm stored grain in the United Kingdom, and the flour beetles (*Tribolium* spp.) which have always been among the commonest pests of stored products throughout the world and have remained so despite the universal use of DDT, lindane and pyrethrins. Fortunately malathion, which has been developed recently for the treatment of foodstuffs and which now has clearance for such applications in the U.S.A., Canada, and the United Kingdom, was shown by Parkin [35] to be highly toxic to these three pests. As a result the problems they cause are diminishing rapidly.

There has also been a growing awareness of the need for good hygiene and proper management to ensure that old stocks do not pile up to infest the new and that infested residues, such as sweepings, do not remain in store. During the war, when insecticides were in short supply, this was perhaps the most important way of protecting stored foodstuffs in the United Kingdom.

Groundnut Storage

One of the most spectacular examples of the use of fumigants, insecticides and good management in food conservation is provided by the groundnut industry of Nigeria. The following account has been taken largely from the 1956–9 Annual Reports of the West African Stored Products Research Unit (W.A.S.P.R.U.) which largely pioneered this work.

Howe [24] described how, between 1946 and 1950, huge stocks of groundnuts accumulated in northern Nigeria and at the railhead in Kano owing to the lack of transport to the port. These stocks, held over from one year to the next, became heavily infested with the Khapra beetle and the flour beetle (*Tribolium castaneum*), which not only destroyed the nuts but increased the free fatty acid content. Most of the groundnuts were stored in "pyramids"—huge stacks containing 700–800 tons of bagged nuts, built in the open on mud plinths and covered during the rains with tarpaulins (Figure 1). Methyl bromide fumigation of these stacks when covered with tarpaulins steadily reduced the incidence of Khapra beetle. Thus, whereas about 111,000 tons or 27·8% of the total crop had to be fumigated in 1952–3 owing to heavy infestation, the amount had fallen by 1959 to a mere 1000 tons, or 0·2% of that season's crop.

Unfortunately the *Tribolium* problem persisted. It was found possible to keep a pyramid fairly free from Khapra beetles after it had been fumigated, since both the larvae and adults could only walk from infested produce nearby, whereas *Tribolium* adults flew with ease on to the stacks. The eventual control of *Tribolium* was a triumph of good management and the use of the right insecticides.

It was found that *Tribolium* could not readily survive in whole shelled nuts. All the nuts stored in Kano and district had been shelled on the farm, using a crude pestle and mortar which caused 70% of the nuts to be broken. To overcome this trouble small hand-operated machines for shelling nuts were introduced for use by the farmers and a cash bonus was paid for shelled nuts of which at least 70% were whole. This was so successful that the percentage of special grade nuts increased from 2·2% of the total tonnage purchased in 1955–6 to 99·9% in 1958–9—quantities of 11,233 and 509,408 tons respectively.

While these improvements were in progress transport difficulties were being surmounted, and in the second half of the 1950s the annual crop which had previously taken a year or more for its complete evacuation was being despatched to the coast within 1–4 months. This also helped to reduce *Tribolium*, yet the pest continued to cause considerable damage until 1956 when malathion was sprayed for the first time on to the pyramids. Counts of the insect collected in a light trap near the stacks showed that by 1959 its numbers had been reduced to less than one-twentieth of their initial level. It is estimated that in 1960 *Tribolium* will cease to be a problem in Kano.

Recent observations show that a moth, *Corcyra cephalonica*, is now developing in considerable quantities on the pyramids. This may possibly be due to the relative failure of malathion against Lepidoptera, compared with gamma-BHC which had been used up to 1957 as a routine spray on the outside of the pyramids. It is, however, unlikely that this moth will cause as much damage or be as difficult to control as the beetles.

A similar success story can be told of the Gambia groundnut crop which forms 97% of that country's exports. Unlike the practice in Nigeria, the nuts are stored in the shell and so are not liable to attack by *Tribolium* or *Trogoderma*, but they are heavily infested with the Bruchid beetle, *Caryedon gonagra*. Green [17] showed in 1954–5 that surface dusting of the large stacks of groundnuts with lindane was enough to rid them of this pest, for *Caryedon* can only breed at the surface of the stacks and thus insecticidal treatment throughout the whole of the bulk was not necessary. Green's work ensured that clean nuts could be stored in the shell in good condition from year to year, and Rhynehart [37] reports that, thanks to close inspection of traders and the threat of disciplinary action by the Gambia Oil Seeds Marketing Board to ensure lindane treatment, conditions had so improved by 1958–9 that only one of 400 samples taken from all parts of the country was infested.

In 1955–6, however, world market considerations necessitated the decortication of the crop before export, and shelling mills were installed. Green [18] found that *Tribolium* could quickly develop to serious proportions within the sacks of shelled nuts from the small numbers present at the time of decortication in the shelling mills. The Gambia authorities are thus facing now the additional menace of *Tribolium* in their shelled nuts, and are tackling the new problem in the now traditional manner by introducing rotational storage, quick shipment after shelling, and good hygiene plus malathion treatment in the mills.

Potato Blight

To illustrate the effects of controlling a plant disease there can be few better subjects than potato blight in the U.K. The fungus responsible is *Phytophthora infestans* (Mnt) de Bary, and records of its pathogenicity, incidence, control and effects on the potato crop are so extensive that it is doubtful whether a more completely documented study of a plant pathogen exists anywhere.

Probably no plant disease has ever caused such a national disaster as the "potato murrain" which afflicted Ireland in 1845, destroying half of the normal crop of 4½ million tons upon which the Irish people depended so largely for food. The disease struck again and again, and between 1845 and 1860 no fewer than 1 million people died of famine and 1½ million were forced to emigrate out of the population of 8½ million. At that time the cause of the disease was a mystery, and many years elapsed before its parasitic nature and the identity of the responsible fungus were established. Its effective control had to await the discovery by Millardet, announced in 1885, that a preparation of copper sulphate and quicklime, now known as Bordeaux Mixture, would prevent a foliage disease —vine mildew; but not until 1891 were trials laid out in England to prove that this fungicide was equally effective in protecting potato foliage against blight.

The application of Bordeaux Mixture or certain other copper fungicides to potato foliage ensures that blight will never again become as destructive as it was in Ireland a century ago, but the fungus is always present in Britain and liable to cause considerable damage whenever warm muggy weather favours its spread. The disease first appears in the south-western counties and extends northwards, and by recording its incidence on the first earlies and keeping a careful watch on conditions of temperature and humidity it is possible to forecast when an outbreak is likely to occur and so to warn farmers in good time when to spray.

In spite of these safeguards, potato blight is still allowed to take a considerable toll of the crop. Little or no damage is done to the first earlies, as these are usually lifted before the disease can destroy enough foliage to affect the yield, but the second earlies and maincrops can suffer badly unless spraying is carried out where and when it is required.

Cox and Large [14] have shown that losses on these crops are almost perfectly correlated with the loss of leaf area due to blight, and they obtained detailed records of the loss of growth time resulting from blight attack in various regions of England and Wales over the seven years 1950–6, three of these being classed as "blight years." Considerable variation in blight incidence occurred from season to season and place to place, but in general the disease appeared first in the south-west about early July and reached the north a month later. By the end of the season maincrop potatoes had usually lost from 5–7 weeks of growth in the south-western zone compared with 1–3 weeks in the northern zone, the fens and the southern zones coming between these extremes. In blight years the crops lost about one week of growth more than the average.

From these calculations Large [28] estimated the average annual avoidable loss in England and Wales over the years 1947–56 to be 7·8% of the crop, or 350,000 tons of potatoes. Considered by regions, the losses were 20% in the south-west and west, 14% in the fens, 7% in the central south and 2% in the north.

Estimates of the amount of avoidable loss prevented have been approached by two routes: the N.A.A.S. farmer survey recorded by Cox and Large [14], and the crop protection industry's production of fungicides used in potatoes [7]. The farmer survey indicated that in recent years only some 30% of the maincrops in England and Wales were protectively treated; the proportion reached 50–60% in the fens and some parts of the southern zone, 20% in the south-western zone and only about 5% in the northern zone. The estimate of potato fungicide consumption in 1958 (a very wet year) made by the industry recently was:

Copper sulphate:
1000 tons at 15 lb./acre = 148,000 acres
Copper oxychloride products:
300 tons at 8 lb./acre = 84,000 acres
Copper oxide products:
200 tons at 6 lb./acre = 75,000 acres
Organic fungicides:
60 tons at 4 lb./acre = 34,000 acres
341,000 acres

This area is slightly more than half the total area of potatoes in England and Wales.

The discrepancy between the results of the two routes is narrow enough to justify a mean estimate that half the potato area is treated. In dry summers considerably less is sprayed, and in wet summers considerably more. It is possible in dry summers (as in 1959) for the spraying to do little good—indeed, the damage caused by wheels can be greater than the saving due to blight control. In wet years of course losses will exceed the mean of 350,000 tons: an avoidable loss of 500,000 tons in a wet summer does not appear unreasonable.

Weed Control in Cereals

The world (excluding U.S.S.R.) consumption of the selective weedkillers 2,4-D and MCPA in 1957 was approximately 35–40,000 tons of active principle. This is sufficient to treat about 80–120 million acres of cereals or, very broadly, 1 acre in 6 of the world's wheat, maize and barley.

The overall picture can be compared with the detailed position in a few countries where surveys of usage have been carried out. Thus a recent investigation in the U.S.A. [6] revealed that in 1959 about 57% of commercial farmers used herbicides of some type, compared with only 45% in 1958. Results that are not dissimilar have been obtained in three detailed surveys of weedkiller usage in the U.K.

Hillebrandt [23] reports that of 22,157 farms of 100 acres and over growing wheat as a cash crop in south-eastern England, 83% treated at least some wheat with weedkiller; the proportion was higher for the larger farms, rising to 98% on farms of over 500 acres. An attempt to correlate value of crop (its yield level) and attractiveness of selective weedkilling showed that the use of weedkillers increased with rise in yields, only 44% of farms harvesting 10–20 cwt./acre making some use of weedkillers as against 97% of farms having yields over 30 cwt.

Rather similar figures were obtained in a survey carried out by the Agricultural Research Council's Unit of Experimental Agronomy at Oxford (now the Weed Research Organization) in 1958 [37], though the number of farms sampled was relatively small. Of 16,000 acres of wheat grown on 60 farms, 47% received herbicidal treatment; of 26,500 acres of barley on 70 farms, 60% was treated; usage on other crops was much smaller, excepting oats with 61%. No distinct correlation was found between farm size and weedkiller usage.

These results are supported also by a survey of usage in England and Wales in 1954 made by Church [11] of Rothamsted in conjunction with the N.A.A.S. More use was made of weedkillers in the dominantly arable farming districts, all of those surveyed being in eastern England, and here in general between a quarter and a half of the cereal fields sampled received weedkillers. In districts having less than about a third of their acreage in tillage crops, 10% or less of the cereal fields were treated.

The examples given from the U.S.A. and the U.K., however, are of essentially high farming areas where weed control gives high returns. In 20 experiments on oats and barley in England, Blackman and Roberts [10] obtained a mean increase in yield of 23·8%; but the sites were selected for their high weed populations and it would be unreasonable to assume that they are representative of more than a small proportion of the cereal area in the U.K. Indeed, during the past 10–15 years, the national average cereal yield has increased by only 30–35% and embraces the effects of improved varieties, higher fertilizer consumption, more accurate timing of sowing and other factors besides weed control.

In a survey of farming opinion in the eastern counties of England, carried out by Nix [33], weedkilling was credited with 10–15% yield increase by the farmer users. Hillebrandt [23] reported that most of the farmers interviewed by her ascribed yield increases of 10–15% to the effect of weed control on their farms.

Nix [33] also examined the relationship between cost of treatment and the ensuing benefit. He concluded that if the average farmer applied the spray with his own equipment, the cost would be repaid in yield alone by an increase of 2·4–3·6% in wheat and 3·2–4·8% in barley if MCPA is used, and 1·6% on wheat if 2,4-D is used. If the spraying is done by a contractor the cost is about 60% above those quoted, and the repaying yield increases therefore become 4·0–5·2% in wheat and 5·3–6·8% in barley. All these returns are surpassed by the farmer opinion surveyed by both Hillebrandt [23] and Nix [33].

By contrast with the cereal areas of the U.S.A. and the U.K., the central Anatolian steppe of Turkey is an area of extensive wheat cultivation (12,000,000 acres) where the average yield is only 8 cwt. per acre and the limiting factor is water availability. In this region a very large and fleshy weed, *Boreava orientalis*, is a serious competitor for soil moisture with the crop (Figure 5). The efficiency of possible weed control practices was investigated there by Fernhurst Research Station staff [25] over a period of two years, on experimental sites covering five districts over a 100 mile radius, applying the weedkillers (four formulations and three strengths) by ground machine and by air. The crop on two sites was taken to harvest and yield increases of 14% and 19·5% were obtained.

The gains in cereal yields obtained by the removal of weed competition seldom appear spectacular, but the herbicides required can be bought by the farmer at prices that make even 5–10% increases economic. When increases averaging 15% are possible over many millions of acres, the reward becomes really big.

CONCLUSION

An attempt has been made in this article to assess the contribution that crop protection can and should make towards the increased prosperity of farmers and the increase of world food supplies.

Crop protection chemicals when properly used provide a means of reducing or avoiding losses in crops and harvested produce, and the last two decades have witnessed striking advances in their development and application. Through these and other improvements in agricultural practice large food surpluses have been built up in some of the more highly developed areas, but these stocks can do little to alleviate the general shortage of food in the less favoured countries, and it is from the underdeveloped territories themselves that the long-term solution of the food problem must come—by improvement of crop and animal husbandry and the use of modern techniques to increase yields and reduce losses.

Increasing the usage of spray chemicals and other crop protection techniques cannot be achieved without parallel improvement in the general standard of agriculture and this, in turn, must be dependent on greater capital investment, raising the farmer's purchasing power and providing him with incentives to grow more and better crops.

All the speakers at the recent symposium on *World Food and Population* (British Association Meeting, Cardiff, September 1960) emphasized that we have at our disposal ample scientific knowledge to solve the world's food problems for several decades to come. The difficulty is to apply that knowledge in the countries where food shortage is most acute. In the particular field of crop protection advances in the shape of new chemicals of greater specificity, lower toxicity to man and animals and lower consumer cost will undoubtedly continue to be made, but even with existing materials and methods a great deal can and must be done now.

The example of cocoa capsid control in Ghana, set out in some detail in this article, illustrates how progress can be made by co-operation on a nationwide scale between farmers, official research and advisory bodies and the crop protection industry. Given the economic urge, capital and far-sighted administrators prepared to listen to their scientific advisers, there is little doubt that similar operations could be carried out in other countries supporting a peasant farming industry, with great benefit to their own prosperity as well as to the world food situation.

ACKNOWLEDGMENT

The writer desires to thank a number of his Fernhurst colleagues, in particular Dr. F. S. Downing, Mr. G. Edmund Jones and Mr. N. Wright, for great help in the preparation of this paper.

REFERENCES

[1] Anon. (1946). *F.A.O. Rep.* Nu/Wa W.P. 3, Washington, D.C.
[2] Anon. (1955). *F.A.O. Commod. Bull.* No. 27.
[3] Anon. (1956). *Statistical and Economic Review* No. 18. United Africa Co. Ltd.
[4] Anon. (1957). *New Gold Coast Fmr.*, **1**, 116.
[5] Anon. (1958). *Rice Plant Diseases in Japan.* Nihon Nohyaku Co. Ltd.
[6] Anon. (1959). *Oil Paint Drug Reptr.* (7th December), p. 44.
[7] Anon. (1960). Press Conference booklet, A.B.M.A.C.
[8] Balzer, A. I. and Cotton, R. T. (1947). *Fmr. Bull. U.S. Dep. Agric.* No. 1906, p. 24.
[9] Bishopp, F. C. (1951). *Agric. Chemicals*, **6**, (2), 38.
[10] Blackman, G. E. and Roberts, H. R. (1950). *J. agric. Sci.*, **40**, 62.
[11] Church, B. M. (1955). *Plant Path.*, **4**, 131.
[12] Cockbill, G. F. (1953). *Rhod. Agric. J.*, **50**, 294–323.
[13] Cotton, R. T. and Gray, H. E. (1948). *F.A.O. Agricultural Studies* No. 2, pp. 35–71. Washington, D.C.
[14] Cox, A. E. and Large, E. C. (1960). *Handb. U.S. Dep. Agric.*, p. 174.
[15] Eden, W. G. (1853). *Leafl. Ala. Agric. Exp. Sta.* No. 40, p. 4.
[16] Engledow, Sir F. (1957). *Plant Protection Conference* 1956, p. 18. Butterworths Scientific Publications, London.
[17] Green, A. A. (1959). *Trop. Sci.*, **1**, 200–5.
[18] Green, A. A. (1960). In the press.
[19] Hale, S. L. (1953). *Rep. Cocoa Conf.*, p. 11.
[20] Hall, D. W. (1955). *Ann. appl. Biol.*, **42**, 85–97.
[21] Hammond, P. S. (1957). *New Gold Coast Fmr.*, **1**, 109.
[22] Harris, W. V. (1938). *Rep. Dep. Agric. Tanganyika*, 1937, pp. 1–8.
[23] Hillebrandt, P. M. (1959). *Fm. Econ. Oxf.*, **9**, 209–24.
[24] Howe, R. W. (1952). *Bull. ent. Res.*, **43**, 111–44.
[25] Jones, G. E. (1952). Unpublished report.
[26] Kockum, S. (1953). *E. Afr. Agric. J.*, **19**, 69–73.
[27] Large, E. C. (1940). *The Advance of the Fungi*, p. 39. Jonathan Cape, London.
[28] Large, E. C. (1958). *Plant Path.*, **7**, 42.
[29] Lefevre, P. C. (1950). *Publ. Inst. Natl. Agron. Congo Belge*, Ser. Sci., No. 48, p. 65.
[30] Lefevre, P. C. (1953). *Bull. Inform. Natl. Etude Agron. Congo Belge*, **2**, 263–8.
[31] Le Pelley, R. and Kockum, S. (1954). *Bull. ent. Res.*, **45**, 295–311.
[32] Mulden, D. and De Silva, R. L. (1960). *6th Commonwealth Mycol. Conf.*
[33] Nix, J. S. (1960). Address to I.C.A.M., King's Lynn, 28th January.
[34] Parkin, E. A. (1956). *Annu. Rev. Ent.*, **1**, 223.
[35] Parkin, E. A. (1958). *J. Sci. Fd Agric.*, **8**, 370.
[36] Pethybridge, G. (1940). *The Potato Blight. Proc. Cornwall R. Polyt. Soc.* (2nd ed.).
[37] Rhynehart, T. (1960). In the press.
[38] Stapley, J. H. and Hammond, P. S. (1959). *Emp. J. exp. Agric.*, **27**, 108.
[39] Woodford, E. K. and Church, B. M. (1959). *Fm. Econ. Oxf.*, **9**, 252.

VETERINARY SCIENCE AND THE WORLD'S FOOD

G. V. Short

(*Imperial Chemical Industries Limited, Pharmaceuticals Division, Wilmslow*)

Animal diseases that can be controlled or eradicated still afflict the underdeveloped countries, threatening the livelihood of all who depend on cattle for food and farm power and sometimes causing national disaster. Much can be done to help. The basic task is to apply our knowledge of livestock husbandry at village level; its fulfilment will demand much money and material as well as patience and sacrifice from those who carry it out.

One of the most profound results of the Second World War was the creation of an international conscience, concerned not only with the preservation of peace but with the provision of food, housing, clothing and education to those nations lacking them. It has been said that food and housing are the most urgent of these, and in expanding the production of food, veterinary science and animal husbandry are of basic importance, especially in the underdeveloped territories of the world.

Only since the Food and Agriculture Organisation of the United Nations has collected and analysed data from every country has it been possible to realize the true impact of animal disease on food production—a realization that might have daunted the boldest spirit were it not for the record of what has been achieved in worse circumstances and with poorer tools than obtain anywhere in the world today. It is heartening, therefore, to view our problems, big though they be, against the backcloth of the great epizootic diseases which were part of our European economy not so long ago and which, but for constant vigilance, might yet be with us.

War has always been associated with the severest epizootics in the past. The relative freedom of Europe from such outbreaks during and after the Second World War is indicative not only of the different methods of feeding troops but of the greater emphasis given to veterinary police measures by the armies involved.

VIRAL DISEASES

Rinderpest

There are no estimations of the part played by rinderpest in the wars of the Middle Ages, though the malnutrition it caused was probably a significant contribution to the death roll ascribed to typhus of troops and the general population. In later times the whole of Europe lost one and a half million cattle (1711–14), Holland being practically cleared of stock. After Napoleon's retreat from Moscow, Austrian troops introduced the disease into Italy, where it killed three million cattle in three years. The war of 1848 cost Austria, Hungary and Italy about 500,000 in losses from the disease, which reappeared in Great Britain in 1865 after an absence of 20 years, causing losses of the same magnitude before spreading once more to Holland, where it killed 270,000 cattle in one year. The war of 1871–2 cost over 80,000 cattle and sheep in France and Germany, but thereafter the disease was progressively controlled until by 1880 only Russia and some parts of the southern Balkans were epizootic areas. The disease was revived and spread during the Balkan war and the First World War, killing six million animals by 1921 throughout Russia and eastern Europe. Belgium was widely infected in 1920, and Greece until 1924.

Asia has often suffered from severe outbreaks, but generally the disease is now endemic in a sporadic and wild form. In India and Pakistan it is still considered the most important disease for eradication, though in terms of livestock losses it may be challenged by helmintic conditions.

The African epidemic was started by the Italian-Abyssinian war, spreading the disease in 1884 from its focus in Egypt throughout Central and South Africa, where it killed two and a half million cattle in two years in the Transvaal and Cape Colony. It then spread to the western equatorial territories, causing enormous losses, and has survived in game animals as a potential threat to cattle husbandry.

In the eighteenth, nineteenth and early twentieth centuries the cost of the disease to the community was in terms of farm traction and protein of animal origin. Although the tractor has now replaced the draft animal throughout most of the European areas previously affected, the old pattern persists in the underdeveloped countries of Asia and Africa. In such territories the loss of a ploughing animal is a disaster for the family or small village afflicted: at one blow they lose the power to cultivate their paddy fields, milk for their children and dung fuel for cooking. Government and international agencies are now doing much to alter the age-old system in which recourse to the moneylender was the only means of again becoming productive, but at the cost of half the crop as interest—the principal remaining unredeemed for generations.

Such a picture was seen in Burma, where during the last war at least a million cattle were slaughtered by the invading armies or lost owing to disease, and rinderpest was rampant at the cessation of hostilities. The effect was catastrophic—and not only locally. Burma was the world's greatest exporter of rice, and the complete loss of her annual surplus of 3 million tons not only ruined her economy but threatened famine to neighbouring Bengal. Recovery has been painfully slow, and even today Burma is producing less rice than she did before the war.

Countries such as Ethiopia with excess meat for sale are restricted in their export plans by the presence of the disease within their boundaries. The considerable revenue derived from the sale abroad of the skins of the Bati goat and Salale sheep, among the highest priced in the world, is also lost.

The present confinement of the disease and the relative security enjoyed by the highly developed agricultural nations are the results of prolonged endeavour, dating from the mid-eighteenth century when Dodson in England tried to apply the principles of the then new vaccination for human smallpox. The subsequent history of the control measures derived from deduction, amendment, trial and error is worth recounting in some detail, since it forms the basis for later work on other virus diseases of livestock.

The first success was scored by the simultaneous injection of virulent virus from a clinically sick animal and serum from a recovered animal, but adequate supplies of consistent materials were difficult to organize while the balance between the virus and serum was very critical. Frank infection often followed, or other dormant conditions were stimulated into clinical disease by the stress of the process.

Vaccines made from diseased tissue in which the virus had been inactivated proved much safer and contributed to effective control of rinderpest and even its eradication from some territories. Disadvantages of this method were the high cost of producing and administering these vaccines, the relatively short period of protection conferred, and complications caused by atypical types of the disease appearing in cattle with waning immunity.

Attenuation of the virus was then developed by passaging it through animals naturally more resistant to it than cattle. Goats were first used to produce very large quantities of goat-adapted virus-vaccine which, though it had originally to be used in the wet state, was a marked advance in the prophylaxis of the disease. Fully susceptible cattle, however, reacted too severely to the vaccine for it to be entirely acceptable, so that passage through other species was studied in the hope of improving its safety. Some success was achieved eventually by using rabbits to produce lapinized virus-vaccine but, although this was much safer for general use, pure-bred cattle still reacted too severely and too often to allow wide acceptance of this method. The further attenuation necessary for such breeds was attained by adaptation of the virus to grow in hatching hens' eggs on the chorio-allantoic membrane to produce the avianized virus-vaccine. Further difficulties appeared at this stage. It was by no means easy in every case to get the virus suitably adapted to the chick embryo so that it would multiply in the developing cells. Sometimes the vaccine produced was too attenuated to confer immunity on some breeds of cattle, while still causing undesirable reactions in others. A combination of both stages of attenuation, first through the rabbit and then through the chick embryo, gave a lapinized-avianized virus-vaccine which causes only marginal reaction in even the most highly sensitive cattle while conferring a good immunity.

The advent of the freeze-drying method of preserving viruses has since made it possible to produce attenuated virus-vaccines in a dry form that is easily handled, durable and of high efficiency, and this technique is now standard. Equipment and training provided by F.A.O. and the close liaison of the O.I.E. (Office International des Epizooties) should change the status of rinderpest from a major problem of veterinary medicine to an exercise in international administration (Figure 2).

There is still need for a clearer realization that disease is no respecter of international boundaries,

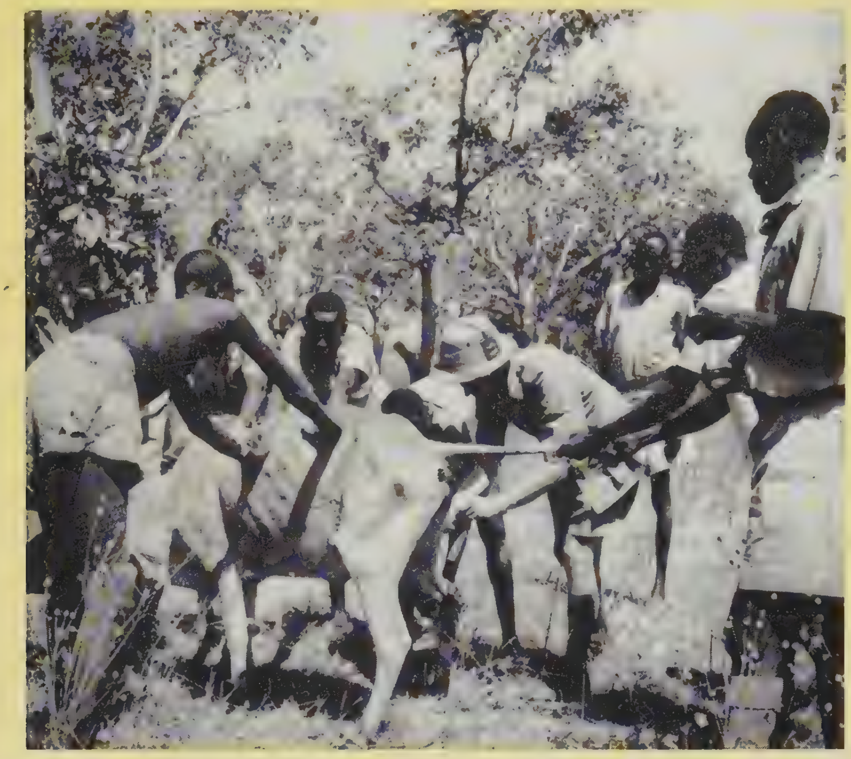

FIG. 1. Protective inoculations against trypanosomiasis enable native cattle to live in and cultivate "fly" areas.

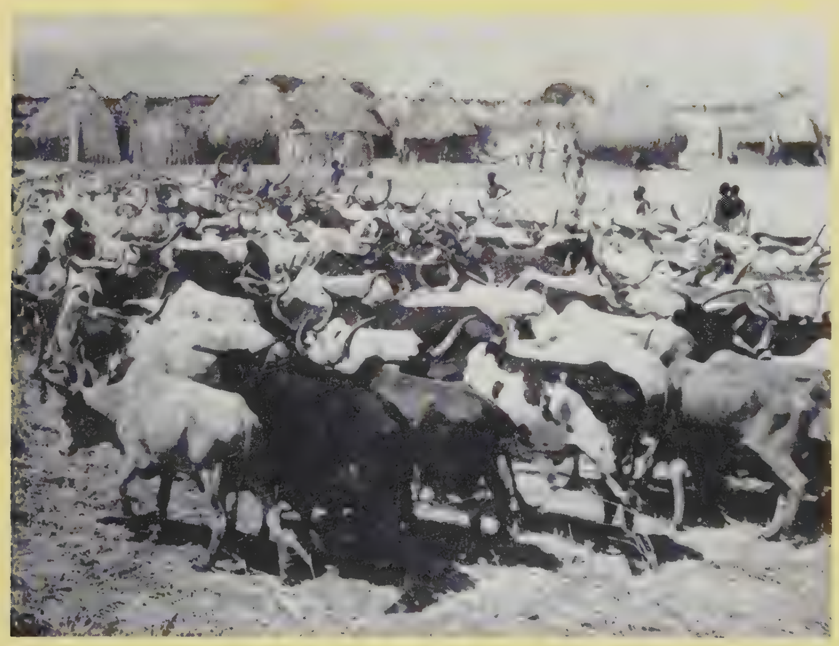

FIG. 2. Rounding up cattle for routine prophylaxis against rinderpest.

but the deliberations of the recent rinderpest conferences in Asia show promise of sound collaboration. The example of Thailand's eradication of the disease within the past few years is a heartening demonstration that success can be achieved by the necessary will and effort to apply the techniques now available.

Treatment of virus diseases generally is confined to the administration of hyper-immune serum in the attempt to confer or fortify sufficient immunity to favour recovery, and to the use of chemotherapy to contain the bacterial multiplication that may occur within tissues weakened by viral invasion and produce secondary conditions of pneumonia or enteritis from which the animal may die.

The modern sulphonamides have thus been successfully used in India, though a great deal more controlled work is needed to show how they may best be employed. Similar trials in Africa have so far not shown the same success. Such work may not be without some personal hazard to field workers in backward districts. In one Indian trial in which half the village cattle were given a sulphonamide in addition to hyper-immune serum, the deaths were one-tenth those of the other half receiving serum alone. Statistical significance was probably not invoked by the "control" villagers in concluding that such unbalanced results might best be corrected by the death of the worker concerned, but he escaped with the loss of his equipment and some dignity.

Foot-and-Mouth Disease

Another condition that has been epizootic in Europe, and could be again in the absence of adequate control, is foot-and-mouth disease. To those concerned specifically in British livestock production rinderpest may seem of academic interest. Foot-and-mouth disease, however, recurs too frequently to be forgotten and is likely to prove troublesome until the international control measures designed and administered by the European Commission for Foot-and-Mouth Disease have been fully implemented throughout Europe, where the outbreak of 1950–1 cost £150 million.

The economics of this disease are composed as much of the losses from production or the cost of compensation as of the heavy recurrent costs of vaccine production and administration. The 500 outbreaks in Great Britain in 1952 cost the nation £2,500,000 in slaughter and compensation; but the provision and administration of a suitable vaccine, even if available, would have cost at least ten times that amount. The old method of obtaining vaccine, using the whole tongue of an infected animal, was very expensive: it has been calculated that to protect the 2·5 million cattle in Holland about 500 cattle weekly would be needed to provide the necessary vaccine, each dose of which would cost about 7s. In contrast, the more recent vaccine prepared from tongue epithelium costs only about 8d. a dose. Some relief to those countries necessarily committed to a policy of vaccination may be hoped for from improved methods of vaccine production by tissue culture.

An essential stage in the control of any virus disease is the identification of the particular strain or strains of virus involved and the preparation of the appropriate vaccine. The campaign against foot-and-mouth disease has been hampered in the past by the lack of an international reference centre for such work. This has now been provided by the World Reference Laboratory, Pirbright, England, on the premises of the Research Institute (Animal Virus Diseases), where all the strains known in Europe, South Africa and Asia are maintained for detailed study. From such co-ordination we may hope for the development of a concerted plan of eradication incorporating towards this end the various policies of slaughter (Great Britain, U.S.A., Eire and Finland), slaughter of affected and vaccination of in-contact animals (Switzerland and Sweden), or total vaccination, with the use of *cordons sanitaires* around the areas involved, practised by other countries in Europe. The need for such a central policy has been emphasized by the recent spread of the Asia I strain of virus as far west as Iran, and of the South Africa Type (S.A.T.) 2 strain as far north as Egypt.

In the Americas a similar watch and ward has been maintained since 1951 by the Pan American Foot-and-Mouth Centre, Rio de Janeiro. While the disease continues to be the most important epizootic problem it has been confined since 1958 to South America, though sporadic outbreaks farther north remain a potential threat to the intensively developed livestock industries of these territories. Canada in 1951, Martinique in 1952, Mexico in 1953 and Aruba in 1954 all saw outbreaks, fortunately stamped out, and this contributed to the decision by Panama and the Central American States to adopt a common slaughter policy financed by a fund to which all subscribe.

New Dangers

The organization that has grown through international effort for the collection of intelligence, diagnosis, vaccine preparation, distribution and application to outbreaks of rinderpest and foot-and-mouth disease has already paid good dividends in the control of "blue tongue" disease of sheep, and is about to be mobilized against African horse sickness—both virus diseases new to Europe, the Middle East and Asia.

Blue tongue, since 1893, was considered as endemic only to certain areas of South Africa, though admittedly troublesome enough locally. The true epizootic nature of this disease was suspected after its diagnosis in Cyprus (1949). The appearance of blue tongue among Israeli sheep (1951) was perhaps not unexpected, but subsequent outbreaks in Texas (1952) and farther west in the U.S.A. (1953) caused concern which was deepened by futher confirmation of the disease in Portugal (1956) and Spain (1958).

The presence of blue tongue naturally precludes all export of sheep, and this prohibition may be applied to exports from countries free of the disease but open to the risk of exported sheep being exposed to infection *en route*.

Control is complicated by reservoirs in cattle, which are usually not clinically affected but whose blood and milk may be highly infective through mechanical spread of the virus by insect (*Culicoides* spp.) vectors. At least 12 virus types and sub-types are known and, as in foot-and-mouth disease, selection must be accurate to provide a useful vaccine. In the Portuguese and Spanish outbreaks the types involved were quickly shown to be those common in South Africa, so that vaccination was highly effective. It is clear, however, that in blue tongue we have a formidable new potential threat to the economy of sheep husbandry throughout the world, and that control of outbreaks will depend on rapid and accurate appreciation of virus types and the preparation and use of the appropriate vaccine as quickly as international co-operation can contrive.

To African horse sickness the same remarks apply. This disease is the latest, and may be the greatest test of the international control machinery in Europe and Asia. Here again is a virus disease long thought "safely" confined to South and Central Africa by aetiological conditions of climate and insect carriers, and, as with blue tongue, its appearance many thousand of miles away in the Middle East has torn up the map of endemic areas, reminding us sharply that animal disease is a constantly evolving process that no static national administration can hope to contain.

African horse sickness is said first to have been described in East Africa by Montclaro in 1569. It has certainly been known in South Africa since 1719, where more than 60,000 horses and mules died in the 1854–5 outbreak; while in a series of outbreaks up to 1923 the Rhodesias lost 90% of their equine population.

The appearance of the disease in Afghanistan and West Pakistan (1958–9) and India (1960) was its first incursion into Asia for many years, and a serious drop in food production is feared in areas that depend heavily on animal agricultural power. Outbreaks have also recently been reported from Iran, Iraq and Syria (U.A.R.), and the disease is suspected in Jordan and Saudi Arabia. Iran had half her equine population of 200,000 affected and had lost 90,000 by mid-June 1960. No figures are yet available from Iraq, but reports describe "battlefield scenes" of dead and dying horses. Throughout the area at present affected there are 12,500,000 equines at risk, to which must be added those of Bulgaria, Greece, Yugoslavia and possibly southern Italy—all countries using much animal power in agriculture.

The conference of directors of veterinary services convened by F.A.O. from the countries affected or threatened will face further complications. Unlike the pattern of the blue tongue virus in Europe, which allowed of the use of South African virus vaccine, the Asiatic strain of African horse sickness differs from the seven strains of virus commonly associated with the disease in South Africa. It is possible that this eighth strain may be entirely individual, so that the South African vaccine may confer no cross-immunity to it when injected into animals exposed to infection in the Middle East and Asia. Should this prove to be so about five months will be needed to produce an effective specific vaccine—or longer if the staff and laboratory facilities required are not readily available. This work has already been started by the despatch of a South African expert to the Razi Institute in Iran to organize the local production of the several million doses of vaccine that will be used before the outbreak can be contained—an undertaking beyond the production capacity of the Onderstepoort Institute in South Africa.

It has been said that the disease in pathology and virulence resembles the human influenza epidemic of 1918. International veterinary medicine and administration will thus face a severe challenge in preventing a similar incidence of morbidity and mortality in the world's equine population.

Perhaps enough has been said about animal virus diseases, without specific reference to Newcastle disease of poultry, swine fever and sheep pox, to review past endeavours in this field and to define in some measure the problems of the future and the part that veterinary science must play in their solution. "New" virus diseases are constantly appearing to challenge research—malignant catarrh, infectious bronchitis, African "sweating" and lumpy skin diseases of cattle, infectious laryngo-tracheitis of poultry and atrophic rhinitis of pigs are typical examples. Fortunately most of them are local in incidence, have been contained and eliminated, or have died out. But there is nothing in our knowledge of these diseases to suggest that, given suitable conditions and a relaxed international veterinary security, they could not become as epizootic in character as any of those reviewed.

BACTERIAL DISEASES

Past successes and future problems in dealing with bacterial infections conform generally to those of the viral diseases. Though their epidemic nature is now less acute, they may nevertheless cause great loss.

Contagious Bovine Pleuo-pneumonia

This disease, known to farmers of the nineteenth century as cattle lung plague, was responsible for the death of 187,000 cattle in the United Kingdom in 1860; but it was eliminated by slaughter in 1898. France became free of it in 1920, and only isolated foci are still to be found in Spain. It is, however, the most important bacterial disease of Australia, where it is endemic throughout the northern fifth of the continent, containing about the same proportion of the cattle population, while cattle traffic from the Indo-Burmese-Chinese "corner" keeps the disease alive in Assam each year. Only extension of the vaccination and police measures successful in the past can reduce the areas affected and eventually the losses suffered.

Tuberculosis

Despite the danger to man of tuberculosis in cattle, its elimination has necessarily been delayed by the more acute and spectacular epizootic diseases. The development of suitable tuberculin sensitivity skin tests and their application by plans designed to suit local economics is one of the most successful stories of twentieth-century veterinary science.

In the U.S.A., with an overall average incidence of about 6%, eradication by tuberculin testing was started in 1917, but took another 23 years to achieve the apparently irreducible minimum of 0·2% in some States. In the United Kingdom, where concentrations of milch cattle are higher and the disease had an incidence of some 30%, control has been complicated by less room for manœuvre and the problem of balancing the desirability of slaughtering reactors against the necessity of conserving milk and meat supplies and guaranteeing their safety for human consumption by strict inspection. The voluntary attestation scheme introduced in 1935, though badly dislocated by wartime conditions, had included 19% of the cattle population by 1950, when the first stage of the area plan was introduced. By the end of 1958 some 85% of the cattle were attested, and by the time this article appears all herds in the U.K. should be so classified. The disease has already been reduced to the possible minimum in Denmark, Sweden and Canada, and is rapidly approaching this level in most of the advanced cattle-raising countries of the world.

The danger to man of bovine tuberculosis has thus receded very markedly in the past 25 years, and indeed there is perhaps more concern at the undoubted possibility of the human type of the disease being spread from man to cattle. Although this strain of infection is not clinically serious in cows, it may excite a positive reaction to routine tuberculin testing and so discredit and confuse the value of such security measures.

Johne's Disease (*Paratuberculosis*)

In countries accepting the elimination of bovine tuberculosis as of first importance it has never been possible to adopt the known protection against paratuberculosis conferred by vaccination because the vaccine sensitized cattle to the tuberculin test. The virtual elimination of bovine tuberculosis now achieved in Great Britain revives hope of reconsidering ways and means of controlling paratuberculosis, which is perhaps the most insidious disease of dairy cattle, though a very careful assessment will have to be made of the risks involved and the confusion to be avoided.

Brucellosis

On the other hand, contagious abortion, or brucellosis of cattle, has long been known as a potential hazard to man. The organism in man may cause prolonged and debilitating fevers, and these have received increased attention recently.

Control of the bovine clinical condition by vaccination has undoubtedly contributed markedly to the programme of pedigree breeding that has made British cattle so desirable for stud purposes. There is some evidence, however, that some form of brucellosis may continue as a sub-clinical infection in such vaccinated animals. The organization and administration so carefully developed for the eradication of bovine tuberculosis and so well proved in the field could well tackle a similar eradication of bovine brucellosis, to the immense benefit of human and veterinary medicine.

Haemorrhagic Septicaemia

Every year this disease continues to kill thousands of cattle, and particularly buffaloes throughout the Far East. It has long been known to be caused by bacteria of the *Pasteurella* group, though their easy recovery from the throats of healthy cattle confused a true understanding of their role in the disease; the name of the disease itself is also misleading, as it does not represent the signs seen in the diseased animal in many areas. The relationship between the organism and stress in producing the clinical condition is reflected in the many popular names current in North America, where "transit fever," "train fever" and "shipping fever" account for heavy losses in cattle transported to the stockyards in Chicago and elsewhere. There is some doubt that the organisms in the American and Asian conditions are identical, but none that the stress in the Asiatic territories is caused by the monsoon and winter rains. The onset of these rains is precipitous, causing a big and sudden drop in the ambient temperature and in the body temperature of cattle exposed to its rigours.

Vaccines used for many years proved of very limited use, probably because the methods then available could not produce good vaccines from the bacterial types essentially concerned with the common pneumonic form of the disease. It is in the emergency treatment of this form that the sulphonamides have proved outstandingly successful in India where appropriate injectable formulations are now to be found in village depots throughout the endemic areas.

Recent work by Dr. Bain (an F.A.O. Veterinary Consultant in India, Ceylon, Burma and Thailand) has led to the development of a vaccine, based on a ketose polysaccharide produced by bacteria grown *in vitro*, and giving good immunity for 6–12 months. This protection will be observed for some years in a group of 10,000 animals in a large paddy swamp in Thailand; preliminary results are very promising.

Mastitis

When we recall how mastitis—the end disease of the end product—can nullify the combined efforts of breeders, nutrition workers, milking machine engineers and dairy farmers, it is hardly surprising that the condition has been the subject of fairly accurate costing during the past few years. While such figures can never be up to date it is now accepted that, excluding "problem" herds, mastitis costs the dairying industry of Great Britain some £10 million yearly, and that of the U.S.A. about £75 million yearly, despite the reduced incidence from 30% pre-war to 10% today. One cannot even guess at what must be the losses—and their consequences in terms of infant malnutrition—in the underdeveloped countries, where the incidence of mastitis is often very high. A survey by the W.H.O. in post-war India showed that of the 16 oz. of milk and milk products considered to be the minimal daily need for adults an average of a bare 4 oz. was available, and that this must decrease with the increasing birth rate.

Much has been achieved by the use of antibiotics as intramammary treatments of the clinical condition, and the advanced countries lose far fewer udder quarters now than formerly from chronic streptococcal mastitis. The U.S.A. now has 20% fewer cows than in 1948, but produces 25% more milk. On the other hand, the antibiotics are tending to become as self-limiting in usefulness in this aspect of veterinary medicine as they are in human hospital practice. With few exceptions, bacteria responsible for the condition are becoming less responsive to antibiotics used singly or in combination. In some cases mixed flora of varying sensitivities have been repeatedly "filtered" until only the more resistant strains are left. In others, strains that were previously sensitive have become progressively more resistant.

Mastitis has hitherto been considered of importance to man solely on the economic loss it causes, but the time may now have come to regard the disease as being of more direct moment. Until recently the strains of staphylococcal bacteria causing hospital sepsis in man and mastitis in cows were thought to be essentially separate. Within the last few months, however, "human" staphylococci have been recovered from clinical cases of mastitis in the U.S.A., the particular strain involved being Type 80/81—the "epidemic strain" of hospitals that is sensitive only to a few of the most recent and carefully restricted antibiotics. There is strong supporting evidence that in these cases it was human carriers who infected the cows, and while it is not yet known to what extent cows so infected may become themselves carriers of this strain, the risk to those in contact with them or their milk before pasteurization is obvious.

An additional risk associated with antibiotic residues in milk is the hypersensitivity they may induce in those drinking it, so that subsequent medical use of the antibiotic may precipitate reactions of varying severity. In America, where mastitis antibiotic therapies are sold freely by drug stores, about 10% of the population is thought to be sensitive to penicillin. In the U.K. two milk surveys have shown a similar risk, and a third survey is proposed to assess the position today.

Although manufacturers of intramammary antibiotic preparations normally state the number of days that must elapse after treatment before milk from a treated quarter is fit for human consumption, individual variations in cows' excretion rates and formulations of widely differing persistence make it difficult for a dairy farmer to be sure that the milk is safe in this respect. A very small amount of antibiotic in the milk may be enough to kill the bacterial "starters" used in the making of cheese—an additional risk to those of bacterial resistance and hypersensitivity.

Attempts to overcome this difficulty have been made by adding various colours to intrammamary preparations, the intention being that no antibiotic should be recoverable from a colourless sample. Technical difficulties have hampered this work, but a promising lead has recently been obtained from Danish work with edible foodstuff dyes, in which the use of a specially dispersible and rapidly excreted formulation of penicillin with a suitable dye addition was shown to give consistent parallelism in the excretion of antibiotic and dye.

"Prevention is better than cure" is an aphorism more appropriate to mastitis than perhaps any other disease—particularly as the chances of eliminating the causative bacteria recede yearly with the expanding pattern of antibiotic resistance. Considerable work has been done on the prophylaxis of the condition and we may expect more attention to be paid to this aspect of control. Still remaining, however, is the problem of eliminating resistant bacteria from infected udders—a problem made more urgent of solution by the possible implication of human "hospital" strains.

INTESTINAL WORMS

A past Director of F.A.O. is stated to have said that if the blood-sucking intestinal worms of domesticated animals could be removed the resulting increase in food would more than satisfy the needs of all the deficient areas in the world.

It is difficult to understand the enormous losses caused by such helminthiases because the infestations lack dramatic impact, and all animals in a flock or herd being affected, there is no visual comparison with healthy stock. Australian research into infestation by *Haemonchus contortus* in sheep has thrown much-needed light on the biology of these parasites and has provided some basis for measuring the losses they cause. A light infestation would contain 100 female *H. contortus*, which would suck 4 ml. of blood from the intestinal mucosa each day in order to produce their average 750,000 ova, and haemorrhage would continue from the punctures for about seven minutes after completion of the meal, so that the total loss of blood would be therefore considerably more. A natural infestation of 1500 females is quite common and would cause a daily loss of blood of well over 100 ml. Disregarding the waste inherent in feeding parasites, well-fed sheep may be able to carry such a load; but poor grazing in a bad season, anaemia from mineral deficiency, or the advent of liver fluke or other disease can quickly kill.

The same workers have also shown that infestation by another parasite, *Ostertagia*, can cause a drop of 50% in the amount that a sheep will eat and a bodyweight loss of 30% within three weeks —a loss that may not be recovered for about a year.

These examples, to which may be added the loss of £3 million yearly in Great Britain from lungworm disease, and crippling losses in wet years from liver fluke disease, may suffice to show that endoparasitic control must come very closely after that of the epizootics in underdeveloped areas, and is mandatory for any concentrated system of livestock husbandry anywhere in the world.

Though our present stock industry could not have been developed or maintained without the application of anthelmintic research to the field, there is still room for a much more extensive use of anthelmintics, particularly of the newer products that have done so much to complete the protection afforded by the older ones.

A great deal has been achieved. Australia's sheep population of nearly 200 million is now limited by pastures rather than by parasites as was once the case, and there is little doubt that a similar application of available knowledge to other sheep-bearing countries could pay a handsome and a quick dividend in wool and mutton. On the other hand, veterinary research still faces the problem of defining and isolating the significant factors of helminths responsible for resistance or immunity in older animals to infestations that so quickly kill younger ones. The irradiated larval vaccine for lungworm disease is a bold step forward in the search for effective vaccines that may take their place with those in use against viral and bacterial diseases.

PROTOZOAL DISEASES

The consumption of protein of animal origin is a fairly accurate index of a people's standard of living, and its increase, especially in undeveloped countries, is reflected very largely in terms of poultry meat and eggs, the economic production of which demands the high concentration of battery and broiler houses. With these conditions comes naturally a high concentration of pathogenic organisms, including the coccidial parasites of chicks and young birds. Poultry farmers need no reminder of the devastating losses that coccidiosis can cause, or of their helplessness to combat it until the advent of the sulphonamides changed the picture completely. Certainly the British broiler industry's production of 100 million birds yearly, and about ten times as many in the U.S.A., would have been impossible without these drugs and the later compounds developed for prophylaxis by routine premedicated feeding.

There is still much to be done before the various aspects of the disease and the nature of the resistance stimulated by the controlled infection are fully understood. But it is now possible for areas poor in animal protein foods to provide at least some of their needs by a livestock industry that, with the necessary technical assistance, is within the capacity of village labour.

Trypanosomiasis

Trypanosomiasis is perhaps the last remaining protozoal scourge now that malaria in man has been controlled by chemotherapy and the elimination from endemic areas of the mosquitoes responsible for its spread. While "sleeping sickness" in man has seen a large measure of control, the equivalent disease in domestic and wild animals in Africa and Asia still presents difficult problems in aetiology and chemotherapy that must be solved before enormous areas of potentially useful agricultural land can be developed.

In Africa the area so denied by the tsetse fly vectors of the disease is about 4½ million square miles, where Africans would gladly settle if their cattle—units of currency in many cases as well as of agricultural power—could live and breed. This huge area is slowly being occupied by man as the bush country essential for tsetse fly propagation is cleared and exploratory settlements are established with cattle protected regularly by chemotherapeutic means (Figure 1). In the past 50 years much has been done, slowly and with difficulty, in circumstances of climate, location and local politics that are rarely better than uncomfortable and often frankly antagonistic. This work, perhaps more than any other in tropical veterinary medicine, demands a dedicated and unremitting application of an exceptional order, and it is understandable that those who have given so much of their lives to this end should feel more anxiety than hope at the developing pattern of independence in some African states.

ECONOMICS

Much has been written on the economics of production but relatively little on those of the losses caused by animal disease and "sub-health." The figures of morbidity and mortality, of bodyweight loss and decline in milk and wool production, are but part of the true assessment.

These losses, considered nationally and internationally, their impact upon the present and future population, and the action needed to balance food against demand were considered in all their complexities at the Symposium on World Food and Population convened by the British Association for the Advancement of Science and at the Eighth International Grasslands Conference during 1960.

Some reference to population pressures related to pasturelands is necessary for an understanding of the animal protein needs and potentialities. Against these standards the true economic and social importance of disease in domestic animals may perhaps more clearly be seen.

It took about 1600 years from the birth of

Christ for the world's population to double itself. Since than a steady compound multiplication pattern has persisted, despite wars and plagues, as farming became more skilful and village settlement tended to replace nomadic patterns of life. In the years 1600–1800 the population doubled again; once more during 1800–1900, and again in the last 60 years, to give a current total of about 3000 million. From this rate of increase it may readily be forecast that the year A.D. 2000 will most probably see a world population of 6000 million—about thirty times as many people as at the beginning of the Christian era.

Although at the present time total world food production exceeds slightly the population growth, this does not and cannot solve the problems of the food deficit areas of Latin America, Africa and south-eastern Asia. Storage and distribution of agricultural surpluses in the productive countries have become increasingly difficult to the point where little improvement seems possible to meet the uneven rates of population growth. While the population of Europe multiplied sixfold during the last 300 years African population only doubled in the same time, and almost all of this increase occurred in the last 50 years. If we are to believe the latest figures from China, the current population of 650 million may be expected to reach 1000 million by 1975.

The intense agricultural development supporting these population growth rates had little animal husbandry counterpart until relatively recently. Julian Huxley, in his essay *On living in a Revolution*, says: "Human evolution has been getting faster and faster—its tempo during recorded history is at least 100,000 times faster than that of pre-human evolution. But the evolution of domestic animals has proceeded far more steadily; until the past hundred years or so it received no such evolutionary stimuli as were administered in the human field by the development of the plough, the spread of Christianity, the Renaissance, the French Revolution, or the Industrial Revolution."

The far more recent realization of the essential nature of animal protein and its relation to human deficiency diseases is the cause of the present concern at the available supplies, and these in turn must depend eventually on the development and use of pastures and forage crops.

Dr. Davies in his paper to the British Association on *Pastoral Systems in Relation to World Food Supplies* showed that the tropical areas most deficient of animal protein had in addition the poorest carrying capacity pastures. In the "very extensive" pattern of husbandry (1–5 "cattle units" per 100 acres) found in many parts of the tropics it is understandable that it requires 20 milch cows to give the same amount of milk as is given by one cow in the "very intensive" pattern of the best farms in Holland, New Zealand and the United Kingdom.

Against this background the significance of recent American work on the conversion of plant material to animal produce becomes clearer. This ratio is stated to lie between 7 : 1 and 10 : 1, and a similar ratio holds for the conversion of meat by meat eaters. To the extent that mankind depends on animal proteins and fats, each pound of bodyweight thus represents about 340–1000 lb. of grain or forage, depending on whether the animal is raised on cultivated or pasture land.

If on this pattern we superimpose those of the animal protein deficiencies throughout the world, the numbers and productivity of the livestock necessary to meet them, the availability and conservation of fodder and pasture for their maintenance, and use what foresight we may have acquired from those studies, we should be able to see the social and political consequences of failure to solve these problems, and to see in sharper focus the true significance and the enormous cost to the national and international community of disease in the animal converters at the top of this food "pyramid."

If we wish for figures to sharpen these facts they are available in abundance. The O.E.E.C. (1952) report *The Control of Livestock Diseases in European Countries* states: "Losses caused by livestock diseases in the United Kingdom have been conservatively estimated at about £80 million per annum, and the bulk of this loss is believed to be ultimately preventable." The bill today of about £150 million—an increase of nearly £10 million yearly—indicates the urgency of this problem. On this basis we may compute an animal loss to Western Europe (1952) of about £600 million, or 15% of the total output of livestock products, but a similar increase will surely apply to give a much higher bill today.

It is evident from older reports that official recognition of these problems was not lacking. The Select Committee on Estimates of the British House of Commons (1947) reported: "In agriculture the effective control of a few outstanding pests or the prevention of one of the main killing diseases would yield a great increase in the volume of food production. These are developments which no country today can afford to neglect." Further afield the U.S.A. Department of Agriculture *Yearbook of Agriculture* (1956) states: "Some 95 million head of cattle were on the United States farms and ranches in 1954, and the losses incurred from livestock diseases, parasites and insects have been estimated at 2·7 billion dollars a year." This is nearly £1000 million. On the other side of the account the eradication of bovine tuberculosis is estimated to save the American livestock industry more than £50 million yearly.

One of the best examples of what disease control in domestic animals can mean to an underdeveloped nation is that of the F.A.O. action in China just after the Second World War. During Japanese occupation of the country very heavy losses among the water-buffaloes essential to the cultivation of paddy fields were caused by slaughter and rinderpest. At the cessation of hostilities it was clear that the control of rinderpest was of prime importance to the recovery of the country, and nearly half a million water-buffaloes were vaccinated accordingly. Many were too weak to survive, but the majority recovered to plough land which yielded more than 100,000 tons of rice.

Recovery

What may be done to overhaul the deficit in animal protein and to induce disease control methods that, with improved husbandry, may eventually lead to a surplus economy? At the outset let it be said that no new knowledge is required; no fundamental discovery awaited. The British Association's deliberations stressed and reiterated the principle—the need of a policy to disseminate present knowledge of livestock husbandry and to ensure its application in the field.

In this, and in the wider aspects of general agricultural development in underdeveloped countries, we are fortunate in having for study the plans, policies and practical experience of India's First and Second Five Year Plans, and their expected development during the Third Five Year Plan (1961–6).

Following the Bengal famine of 1942–3, Professor A. V. Hill spent five months in India at the invitation of the Government to advise on future development. His report, *Scientific Research in India*, published in India and reprinted by the Royal Society in England, was followed by various others and by letters to the press, in one of which, "The Indian People—Nutrition and Disease" (*The Times*, 1st June 1944), he stressed that disaster on a scale unknown even in India's history might occur before very long unless immediate steps were taken with all the resources of science and technology and the fullest co-operation of all men of good will to meet the need of the rapidly expanding population for more and better food. As a result an anonymous team of experts, after an exhaustive study of the situation, published *A Food Plan for India* under the auspices of the Royal Institute of International Affairs in 1945. In this is set out, step by step, the organization and administration necessary to establish and maintain a network of instructional centres for the translation of known theory into new practice *at village level* in all aspects of agricultural and livestock improvement.

On this plan the Indian Government founded and has extended its Five Year Plan periods, with more than 500 Key Village Centres and National Extension Service Areas as the points of instruction and demonstration. The illiterate Indian herder or farmer is certainly as conservative in his distorted views and malpractices as are any others, and for the very good reason that he has no margin for experimentation. He cannot afford to lose, and he has been the object of exhortation and advice from too many quarters too often in the past. His response is that of the bazaar crowds: hooted at by every car and shouted at by every cyclist—he takes no notice. He cannot be got to listen by shouting louder, but he can be interested in the practical proof of a theory by a demonstration by someone he trusts on his own animals in his own village with his neighbours watching in the wings to detect any trickery. At the end of a successful demonstration he will be prepared to think about it, which means to talk it over at very great length with his neighbours.

Meanwhile, the demonstrator must be prepared to live patiently with the people. Nothing can be hurried, for does not the magician in the bazaar deceive the eye by the speed of his manipulations? Over-hasty thought may cause the peasant to lose, and he cannot afford to lose, therefore he thinks slowly. Eventually he may ask for a repeat performance, just to be sure that the first success was not accidental. If the second demonstration is not given as slowly and as patiently as was the first, all is lost. The peasant is convinced that all was not as it seemed, though he was unable to detect just what it was, otherwise why the impatience?

It follows that men with a natural aptitude for Key Village or N.E.S. work are hard to find and train. Yet they must be found and trained. A good though belated start has been made in the training of veterinarians in India where, at the start of independence, there were three veterinary colleges giving indifferent instruction. Today there are seventeen veterinary colleges affiliated to universities with curricula of five years. Even so, some colleges are working a double shift, with classes in the early morning and late at night, in an effort to train the men necessary to improve the ratio of one veterinarian to 130,000 animals that obtained at the time of independence. The majority of the students are Government assisted, and it has been suggested that all graduates should spend at least two years in village extension work before becoming eligible for an urban appointment.

Though India will remain a food importing country for many years, the success of her efforts to bring science and technology out of the laboratories to live in the fields cannot be gainsaid. She has made mistakes, particularly in the First Five Year Plan period, when in the first fine careless rapture of industrialization it may not have been realized clearly enough that each man attracted from the land into a factory meant one less man producing food and one more man demanding it. But she has profited by experience and is confident of reducing from 65% to 60% the proportion of her population engaged in agriculture during 1961–6—an increase in agricultural efficiency of at least 20%.

Extension

What has been done and is being done in India should in principle apply to other underdeveloped countries, but animal husbandry and disease control problems vary widely in kind and degree.

In Pakistan, where the Second Five Year Plan period has just started, the task is going to be longer, and it will be harder to achieve a smaller success in meeting the greater dependence of the Pakistani on meat. These difficulties have been heavily aggravated by the failure of the previous four Governments to realize that propaganda and instruction, to be effective, must permeate the community through village outlets rather than through District directives. The Village Aid Organization, theoretically admirable and neglected, is to be the centre for the development planned. This will mean that those charged with implementing the policy will be required to live in the main village serving the surrounding countryside rather than in the nearest big town.

Some idea of the problem of animal disease control and husbandry development may be gained from the general agricultural pattern of the country. West Pakistan's 198 million acres and East Pakistan's 36 million acres are 80% uncultivated, sparsely forested or unclassified. Alternating flood and drought, and erosion and denial of cultivation by efflorescence of subsoil salt account for some of the lowest yields in the world, which must yet suffice for 80 million people, increasing at 2% yearly. Yet these are the people who have now been told that the economic survival of their country depends upon their changing, as quickly as possible, from a subsistence to a cash agriculture. To help them it is hoped to train by 1965 enough village workers to instruct 85% of the rural population, but West Pakistan still has only one veterinary college and East Pakistan is trying to put another on a firm foundation.

It has been said that animal husbandry in underdeveloped countries is not simply technology, nor simply the volume of resources invested in technology. Animal husbandry is agriculture, and agriculture is the people. For these countries there is no turning aside from this, no escape, no short cut. It will be a long, obscure, tedious business costing much in money, material, patience and sacrifice. Veterinary science has much that must be used as men are trained to apply it. A great deal has been done by F.A.O. teams in the field and staff in overseas universities, but perhaps more might be done for the training of students from deficit countries in the colleges and universities of Europe and America. The example of Israel, herself scarcely developed, in offering 1000 places to overseas students for training in general technology is a case in point.

Much has been done in the past; more is being done today; very much more remains to be done—and it may be too late tomorrow. In the two days required to write this article the world's population has increased by a net 300,000. The world's peace requires that they be fed.

BOOK REVIEWS

Principles for British Agricultural Policy. Edited by H. T. Williams. Pp. xiii+317, with line illustrations. Published for the Nuffield Foundation by Oxford University Press, London. 1960. 18s. net.

There have been surprisingly few reviews of agricultural policy in recent years and the present volume is therefore welcome. While the report is based on an investigation financed by the Nuffield Foundation, its present form is mainly due to Sir Frank Engledow, an authority on world agriculture, and Mr. H. T. Williams, formerly head of the Economics Department in the Ministry of Agriculture. For this reason, the opening chapters on the recent history of agricultural policy are illuminating, for both authors played a part in its formulation.

As the authors state, the taxpayer finds each year about £250 million in grants and subsidies, and is entitled to ask whether he is obtaining his money's worth and whether agriculture is being shaped to meet national needs. Several criteria are used to judge its worth. Does British farming provide any special nutritional needs? The answer is none that calls for any special government intervention. Such advantages as freshness can, and no doubt will, be paid for by the customer. Does farming provide a way of life that deserves special consideration? The answer is that while the countryman has certain amenities and inevitable disadvantages, these are not of sufficient importance to dictate policy.

The authors then pass to the two questions that obviously interest them most. The first is the kind of agriculture that scientific knowledge and farming experience appear to dictate. A strong plea is made for mixed farming and for the inclusion of leys in the rotation.

While the advocacy of mixed farming is justified, many farmers already have too many enterprises and some of these are invariably neglected. Increasing competition is driving farmers to specialize and simplify their farming systems to some extent. This is not (as the authors sometimes seem to imply) necessarily inconsistent with good farming and a reasonable rotation

A strong case can be made out for leys instead of permanent pasture. If, however, the use of long leys in an arable rotation means the replacing of cash crops by cattle or sheep, the farm output will fall—even if subsequent crop yields were raised by the 7% suggested. This section does indeed reveal the lack of exact knowledge of the nature of soil fertility and the precise effect of farming practices on it. For this reason, the recommendations, although sound, are necessarily less specific than one would like.

The final question asked is whether British farming justifies special treatment as a source of food in a future war. This is considered to be the chief role of farming, and detailed suggestions are given for the accumulation of strategic reserves of fertilizers, machinery and tractor fuel, so that production can continue uninterrupted by blockade. This argument is worth careful consideration by the authorities—if it is believed that Britain is likely to be under siege for a long period. On the other hand, if a short atomic war is expected, it might be better to spend some more of our £250 million on missiles, anti-submarine devices, deep shelters and a food store.

It would have been interesting to see this study carried further with more suggestions on the exact pattern of farming required and the economic inducements that would be required to bring it into being. Some consideration of the place of British farming alongside Commonwealth and European farming would also have been welcome. Not all of these considerations can, however, be covered in one book and the authors have performed a valuable service by presenting the background and by clearing away some of the less valid pleas for special help. They have left it to others to formulate a detailed policy. As such, this book is a valuable contribution to the subject.

F. G. STURROCK

Strontium 90 in Milk and Agricultural Materials in the United Kingdom, 1958–59. (Agricultural Research Council Radiobiological Laboratory Report No. 2.) Pp. xi+91, with line illustrations. H.M.S.O., London. 1960. 5s. net.

In all parts of the world today there is apprehension about the possible effects of radioactive products of atomic explosions on the health of mankind. A few have long been aware of this hazard from radioactive elements but only since the first atomic explosion in 1945 has this awareness become general. While some of the fission products have short half-lives and may be relatively harmless, others have long half-lives and are potential sources of danger. Such is strontium 90 which has a half-life of over 20 years and, via herbage and milk, can find its way into the bone structures of man and other animals. It is clearly very important to study the extent to which food supplies are being contaminated by such radioactive elements.

This is the second report of the Radiobiological laboratory at Wantage on the contamination of human diet with strontium 90 and covers the period 1958–59. The report is divided into three parts and has seven appendices and good summaries. Part I deals first with the organization of the survey and the sources of the samples. Tables are given comparing the twelve-month mean value of strontium 90 in milk in 1958 and 1959 and graphs showing the trends month by month. The results suggest that the twelve-month mean values will not rise further as a result of the strontium 90 already there, but would in fact decline relatively rapidly if weapon-testing ceased. Part II is a survey of strontium 90 in perennial pastures and animal bones and the causes of variability from area to area. On average the upper 10 cm. of the soil contains about two-thirds of the estimated cumulative deposit, the remainder passing apparently by surface wash to the streams. The distribution of strontium 90 between the tips and bases of grasses is considered in some detail. Part III outlines the experimental strides that provided the basic data for parts I and II.

This is a most useful report. It does not minimize the difficulties involved in arriving at a satisfactory estimate of strontium 90 in milk and other foods. As so often happens in investigations of this kind, it is helping, incidentally, to throw light on other fields such as the uptake of calcium from soils. A few small errors have been observed but these in no way detract from the value of the report.

A. J. LOW

Plants and Environment: a Textbook of Plant Autecology. R. F. Daubenmire. Second edition. Pp. xi+422, with line and half-tone illustrations. John Wiley & Sons Inc., New York. 1959. 56s. net.

The first edition of this book was published in 1947. This new edition has a revised bibliography (773 instead of 612 items) and there are some changes in the text. A few sections have been omitted; there are many minor additions of a sentence or paragraph to introduce new references; there are longer insertions extending to a page or so of text, in particular concerning frost-churning of soils, atmospheric pollution, temperature measurement, and adaptations related to fire; and about a quarter of the chapter on the environmental complex has been rewritten. Thus the content of the book has been brought more up to date, but there has been no change in its general plan or outlook.

The relations of the plant with its environment can be approached in two ways: first, there is the descriptive approach of the field worker or natural historian, which covers a wide range of phenomena; secondly, there is the quantitative approach of the meteorologist, pedologist, and whole-plant physiologist, which seeks in the first instance to illuminate general and normal relationships rather than special ones. Nowadays these two aspects are uniting in certain fields.

Professor Daubenmire adopts the former, descriptive approach, and this enables him to discuss a wide range of subjects, including various unusual and interesting relationships. It is a pity, however, that he tends to avoid quantitative treatments even where these are available. For example, it is depressing to see the statement (based on a 30-year-old review) that "Nor can the photosynthetic rate be predicted when all measurable factors are known"; for a great deal of work on dry-matter production has analysed with considerable success its quantitative control by leaf area, light receipt, temperature, and other factors. Professor Daubenmire doubts the usefulness of such approaches; he states that "mathematical expressions of the relations between environment and response are of value only as an aid in the interpretation of field observations." But ecological work is becoming increasingly concerned with the general mathematical expressions which underlie (and are more fundamental than) particular field observations; and by ignoring such trends this book begins to fall behind current ecological thought.

Moreover, mistakes occur where quantitative relations are dealt with, e.g. "the temperature coefficient [has] very high values on approaching the optimum temperature" (p. 180) is obviously erroneous, since its value is zero at the optimum, the highest values often occurring just above the lower cardinal point; "light energy can be expressed as lux-seconds" (p. 218) brings confusion between measurement of energy and assessment of visual intensity of illumination; "sciophytes may use as much as 73% of the light energy available to them in the manufacture of sugar" (p. 232) is a gross overestimate. These and other errors and naïveties are most unfortunate, since the rest of the book, where it is essentially descriptive, is excellent.

"Plants and Environment" discusses in turn the various ecological factors: soil, water, temperature, light, the atmosphere, the biotic factor, and fire. In general, attention is given mainly to the environment, secondly to adaptations of plants, and least of all to the direct responses of plants to their environments. The last two chapters concern "The environmental complex" and "Ecological adaptations". The text is lucid and interesting, and the treatment is perceptive, balanced, and full, including a great deal of material not offered in other textbooks. The extensive reference list (limited to papers in English) is particularly valuable in its inclusion of unfamiliar material. The numerous photographs—five more than in the first edition—also contribute usefully to the book.

Special ecological terms are printed in italic (not bold, as stated in the preface) and are defined where they first appear. Some readers may feel that these terms are sprinkled too liberally, especially where their spelling varies, e.g. phreatophytes (p. 114) and phraeatophytes (p. 142), endozoochor (p. 302) and endozoochore (p. 413).

This book will be of interest not only to pure ecologists, for whom it is primarily intended, but also to applied ecologists; for many of the principles discussed are equally relevant in applied fields, and material from agriculture, horticulture, and forestry occurs in both text and bibliography. For the research worker the book may offer a lead to ideas and literature in an unfamiliar aspect of environmental autecology, and for students it provides (excepting its weakness in quantitative matters) a very good descriptive account of the ecology of the plant environment.

J. WARREN WILSON

Plant Growth Substances. L. J. Audus. Second edition, revised, Pp. XXII+553, with one colour plate and line and halftone illustrations. Leonard Hill (Books) Ltd., London. 1959. 65s. net.

The discovery, some 25 years ago, that the growth of plants can be influenced by extremely small amounts of certain synthetic chemicals, opened up new areas of chemical, physiological and agricultural research. This book, which deals in a most creditable manner with all these aspects, reveals the extensive progress which has since been made.

The arrangement is similar to that of the first edition, published in 1953, with the addition of a most useful new chapter dealing with the mechanism of auxin action from the physiological viewpoint. There has also been considerable expansion of other chapters; for example, "The Chemistry of Auxins" has been enlarged to include description and properties of the many new synthetic growth substances which have been produced during the past few years. Attention is also given here to recent research in relationships between chemical structure and plant growth-regulating activity, and the mode of action of auxins is considered both from the chemical and physico-chemical viewpoints.

Other chapters have been expanded; a more detailed treatment is given, for example, to flowering control and chemical control of sexual processes in lower plants; growth stimulation in normal fruits is described and the use of growth substances in plant breeding receives more detailed consideration. The chapter on abscission and the one dealing with hormones in relation to reproduction have both been enlarged, and there is more detailed treatment of the use of synthetic growth substances for selective weed control.

While the greater part of the book is concerned with the auxins, some attention is given to more recently discovered naturally occurring substances, such as the gibberellins and kinetins, upon which plant growth processes also depend.

The six useful appendices which appeared in the first edition are included with slight modifications in the present volume. These deal with the use of growth substances for the rooting of cuttings, the setting of fruit, preventing the pre-harvest drop of apples and for inducing abscission.

Inevitably, with all the new additions, the volume has increased in size substantially. There is no doubt, however, that the author has succeeded in producing the most comprehensive and up-to-date book which has yet appeared on this wide and important subject. There is something in its pages for all those who are interested in plant growth and its regulation with chemicals. With its strong emphasis on basic science, however, this is essentially a volume for the student and research worker who is directly interested in the study and control of plant growth. It will find wide use as a reference book and will fulfil a great need in providing the reader with a comprehensive view of this rapidly developing field of research.

The book, although somewhat expensive, is well produced and contains many excellent diagrams and plates.

R. L. WAIN

Printed in Great Britain at THE KYNOCH PRESS, *Birmingham*